I. C. 6966 OCTOBER 1937

DEPARTMENT OF THE INTERIOR

UNITED STATES BUREAU OF MINES
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INFORMATION CIRCULAR

OCCURRENCE AND TREATMENT OF MERCURY ORE AT SMALL MINES

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BY

M. W. VON BERNEWITZ

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OCCURRENCE AND TREATMENT OF MERCURY ORE AT SMALL MINES[1]

By M. W. von Bernewitz[2]

INTRODUCTION

The Bureau of Mines receives frequent requests for information on the treatment of mercury ores, but as its own and almost all other publications on mercury are out of print, the Bureau has prepared this circular on the metal for the prospector and operator of small mines and plants.

Mercury, commonly though improperly termed "quicksilver", is the only common metal that is liquid at ordinary temperatures. Mercury is used in the amalgamation of gold and silver, in power boilers, explosives, frictionless bearings, laboratory apparatus, lamps, medicine, paint, rectifiers, and for "silvering." The last mentioned is being superseded by silvering with silver. The use of mercury boilers may increase when they are thoroughly understood, but amalgamation is being replaced to some extent by the use of corduroy and other collecting mediums, such as jigs and flotation cells.

Probably the term "quicksilver" or "quick" will always be used by some persons, but the use of "mercury" is growing. The latest dictionaries favor mercury, styling quicksilver as colloquial. Even in the classified telephone directories of Chicago and New York the references are under Mercury; under Quicksilver it says "See Mercury." In Los Angeles the references are under Mercury. San Francisco, the principal market, sticks to Quicksilver in its directory.

ACKNOWLEDGMENTS

Credit for material abstracted from published reports and personal statements is given throughout the text and in footnotes. The Bureau of Mines adds special acknowledgment to the following for detailed information: W. W. Bradley, State mineralogist, San Francisco, Calif.; George E. Connolly, mechanical engineer, Pacific Foundry Co., San Francisco, Calif; and M. Levit, Joshua Hendy Iron Works, machinery manufacturers, San Francisco, Calif; also H. W. Gould, specialist in mercury, San Francisco, California.

1/ The Bureau of Mines will welcome the reprinting of this paper, provided that the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6966."

2/ Assistant mining and metallurgical engineer, Metallurgical Division, U. S. Bureau of Mines.

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PROSPECTING

Simple Geology

Figure 1, reproduced from Minerals Yearbook 1935, shows the situation of the mercury deposits known in the western United States.

Mercury is sometimes found in small quantities as the metal, but the main source is cinnabar, the sulphide HgS. Pyrite and marcasite often are associated with the mineral, as are small quantities of other sulphides as arsenic and antimony. Native sulphur and bituminous matter also occur in some ores, according to Duschak and Schuette[3], who say:

> Mercury ore is found in rocks of all geologic ages and classes; hence, the gangue material of the ore differs in different mines and often in the same mine. The common gangue rocks are limestone, calcareous shales, sandstone, serpentine, chert, andesite, basalt, and rhyolite. This great variety of gangue minerals means a corresponding variation in the physical characteristics of the ore. Two general types of cinnabar ore can be distinguished, namely: (1) Disseminated [finely distributed] ore, in which the cinnabar has impregnated a more or less fine-grained or lightly brecciated [fragmental] gangue; and (2) ores deposited in fissures and cracks of the country rock. In at least one body of disseminated ore the cinnabar was precipitated simultaneously with the amorphous [uncrystallized] silica cementing the brecciated rock. The second type of ore merges into the first as the fissures and cracks become minute; at its other extreme are large veins and bodies of almost pure cinnabar, sharply separated from the enclosing gangue.
>
> Both types of ore may form high-grade or low-grade ore bodies, may be hard or soft, may break into coarse or fine fragments, may show the red cinnabar plainly or may not, and may contain any of the associated minerals already mentioned.

Schuette[4] considers that a thorough understanding of the geology is of fundamental importance in mercury mining. In his paper, which merits attention, he describes deposits in all parts of the world and illustrates many by sketches that are easily understood and of practical use in prospecting.

3/ Duschak, L. H., and Schuette, C. N., The Metallurgy of Quicksilver: Bull. 222, Bureau of Mines, 1925, 173 pp. (Out of print).

4/ Schuette, C. N., Occurrence of Quicksilver Orebodies: Tech. Pub. 335, Am. Inst. Min. and Met. Engrs., New York, 1930, 88 pp. (90 cents.)

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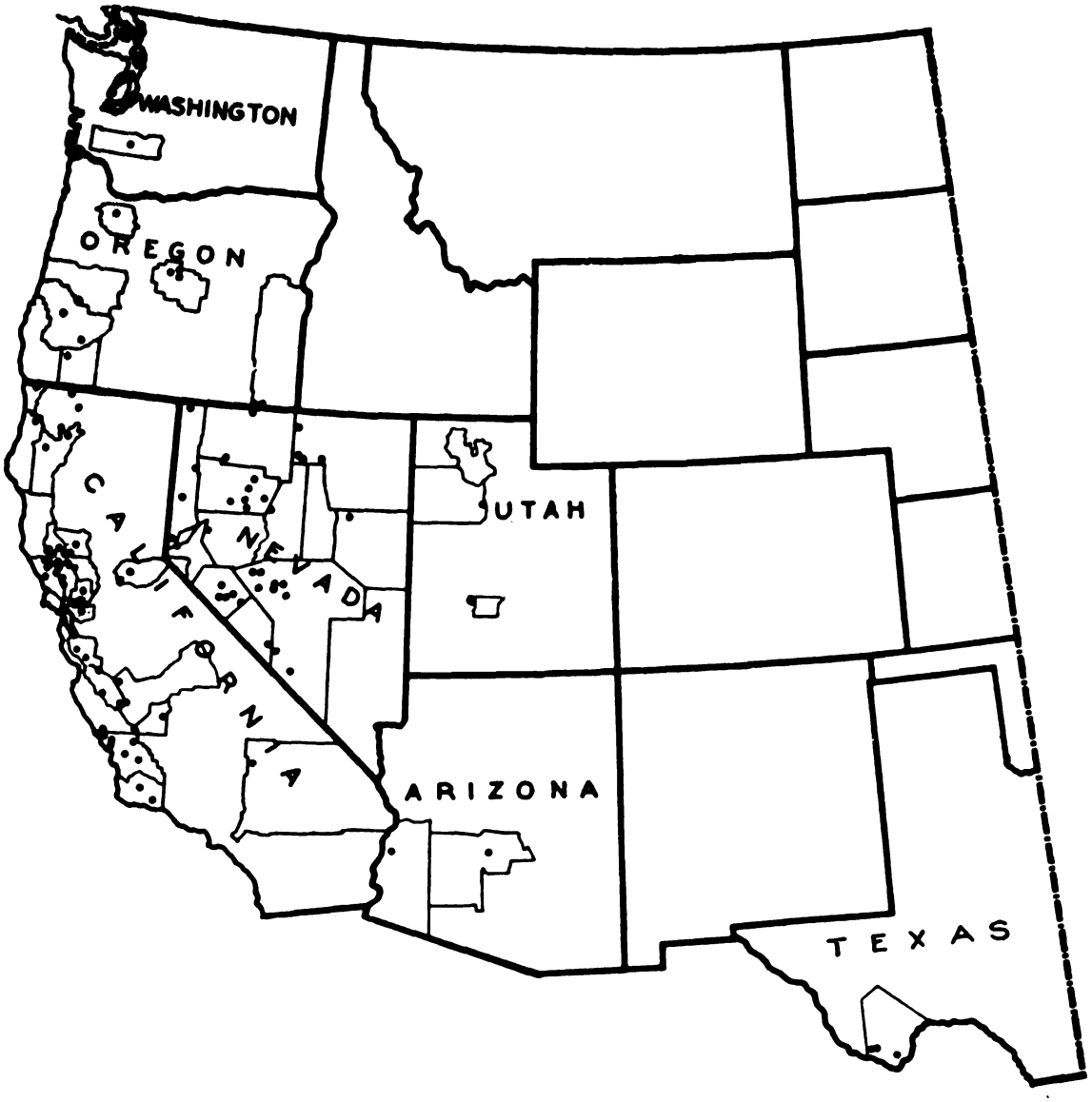

Figure 1.— Location of mercury mines and prospects, western United States.

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Schuette, before Le Conte Geological Club, California, on December 5, 1936, read a paper entitled The Geology of Quicksilver Ore Deposits. This was published in the California Journal of Mines and Geology (Division of Mines, San Francisco) for January, 1937. Seven photographs and four sketches explain the deposition of mercury deposits, which are formed only by primary enrichment. The source of the ore is a deep-seated rock magma; the ascending mineral-bearing solutions were alkaline; the deposits are always found under a gouge or caprock more dense than the receptacle rock in which the ore forms; the ore forms in preexisting voids in the rock; the caprock forms a trap and the more perfect it is the larger and richer arethe orebodies formed under it; the ore is nearly always cinnabar. The caprock may be shale strata, silicified beds, clay, or basalt; the mineralized rocks may be sandstone, limestone, or breccia. Although trapped orebodies may be extensive and high grade, they do not necessarily outcrop, thus rendering prospecting difficult. The few important foreign mercury producers are perfect traps structurally and each is or was the one and only really large mine in its region. California had and still has a dozen large mines and dozens of smaller ones, all with the nearly perfect structure. Oregon has some of these.

Schuette states that the mercury mineralization of Nevada is as widespread as that of California, but the carrier solutions came up the large, deep boundary faults, reached the surface quickly, had less breccia in which to form, and less gouges under which to be trapped, therefore the Nevada deposits are small in tonnage, shallow, and confined to small areas.

In Texas the most productive horizon is under the Del Rio clay which lies on limestone. Likewise in Mexico, more or less.

CINNABAR

Cinnabar contains 86 percent mercury and 14 percent sulphur. Normally, it is bright red or crimson. As a rule, this makes it easy to distinguish from other minerals and in sorting operation. (Cobalt bloom is also crimson, but it is generally earthy, not crystalline.) However, some impure cinnabar is brownish, almost identical with certain forms of iron oxide, also found in the ore. If this ore is wetted, the cinnabar at once shows its characteristic color. Cinnabar has a specific gravity of 8 and a hardness of 2 to 2.5, and weighs 560 pounds per cubic foot. When heated to a temperature of 500° to 600° C. (932° to 1,112° F.), depending on the texture of the ore, cinnabar will give up its mercury in the form of a vapor, which, when condensed with water or air, yields liquid mercury. The metal has a specific gravity of 13, and a cubic foot of it weighs 800 pounds.

Occurrences of Cinnabar by States

The United States Geological Survey has examined all important mercury deposits in the United States and has published many reports thereon.

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McCaskey's[5] chapters, Quicksilver, for 1910 and 1911 in Mineral Resources of the United States include bibliographies on previous writings. The chapter for 1911 is somewhat similar to the Economic Papers now published by the United States Bureau of Mines because it covers the production, occurrence, mineralogy, development, and trade in mercury. The reports of the Survey are worth studying by anyone who is interested in the metal. Each year prior to 1925, when the Bureau of Mines took over its publication and in 1933 changed its title to Minerals Yearbook, the Geological Survey had prepared a chapter on Quicksilver in Mineral Resources.

Arizona

A small quantity of mercury was produced in Arizona during 1935, as in 1934, at one property, and for several years the output of the State has been small. According to Lausen and Gardner[6], writing 10 years ago, some of the deposits in the three principal districts were promising, and further prospecting in other areas, especially along the schist belt, was expected to reveal workable deposits. Some idea of the occurrence of mercury in Arizona may be gained from the following notes, based on this report:

Mercury has been detected in scattered areas of Arizona, but the deposits that have been worked are in the Dome Rock Mountains in northern Yuma County, near the western boundary of the State; in Copper Basin, southwest of Prescott; in the Phoenix Mountains; and in the Mazatzal Mountains, north of the Roosevelt Dam. These districts are spotted in figure 2.

Ten miles or so southwesterly from Quartzite is Farrar Peak, the highest point in the Dome Rock Range, which is composed mainly of schist. A shattered quartz vein being worked occupied a fault-fissure in the schists. It was 5 to 6 feet wide, the best ore being at the center with some cinnabar at each side in the crushed vein material. Cinnabar was the principal mercury mineral, but metacinnabarite, the black variety, was found also, sometimes coating the cinnabar.

In Copper Basin, 10 miles southwest of Prescott, Yavapai County, at an elevation of 5,300 feet or more, the mercury deposits occur as siliceous veins in a mass of granite that has been intruded by an irregular mass of diabase and by dikes of andesite and rhyolite. As a rule, the veins lie along the dikes, although some are entirely in granite and some in gabbro. They occupy fault fissures filled with crushed fragments of the wall rock. The cinnabar is closely associated with pyrite, the former often coating the latter. Cinnabar also occurs as minute grains or tiny veinlets traversing chalcedonic quartz.

5/ McCaskey, H. D., Quicksilver: Mineral Resources of the United States, U. S. Geological Survey, Part I, 1910 and 1911, pp. 693-710 and 889-921.

6/ Lausen, Carl, and Gardner, E. D., Quicksilver (Mercury) Resources of Arizona: Bull. 122, University of Arizona, 1927, 112 pp.

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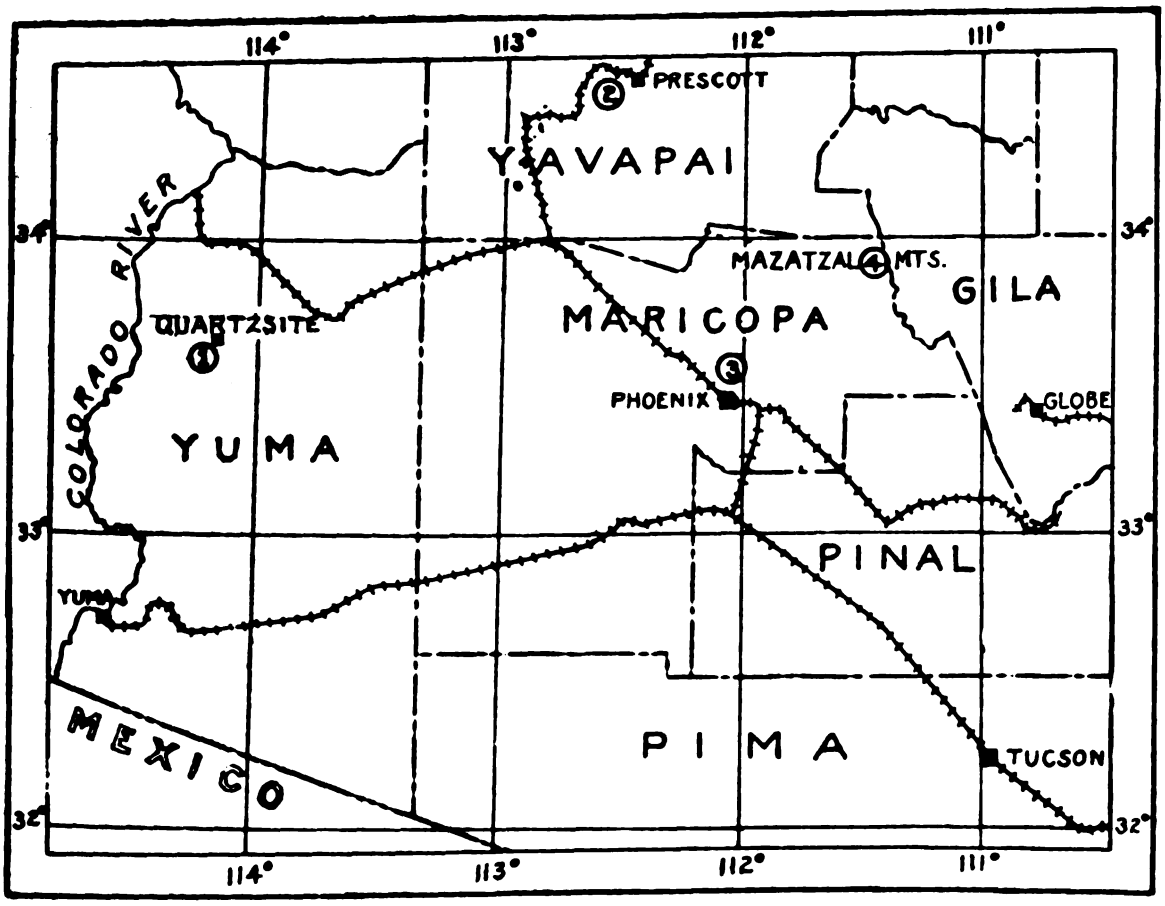

Figure 2.— Distribution of mercury deposits in Arizona.

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The Phoenix Mountains are 8 miles in length and lie 11 miles north of Phoenix. Outcrops of mercury ore are rather inconspicuous. Veinlets usually not over 2 inches in width and more often less than 1 inch traverse the schists, mostly paralleling the schistosity. The ore occurs as well-defined shoots consisting of narrow veinlets and disseminated cinnabar in the fault-gouge along shear-zones or fractures. It has also been observed as disseminated cinnabar in the body of the schist and as thin films on joint-planes of the rock.

At the time the report mentioned was written, the Mazatzal district offered possibilities of developing mercury ore. The mineralized area is drained by Sycamore Creek and Tonto Creek. The deposits are on Alder Creek, at over 4,000 feet, and on Slate Creek, at under 3,000 feet. The country is rugged. The ore consists of veinlets cutting the schists or as thin films on fracture-planes. Some disseminated cinnabar in the schist was observed. The veinlets range from a fraction of an inch to 6 inches or more in width, but 2 inches or more is exceptional. As a rule, these stringers are parallel, and when numerous the rock constitutes ore.

Mercury-bearing shales. - According to Lausen1/, the Chinle shales of northern Arizona, extending southward and then eastward from Lees Ferry, which is 12 miles of the Utah line, may contain a large tonnage of mercury. This formation also extends northward into Utah and eastward into New Mexico. In the immediate vicinity of Lees Ferry the Chinle shales rest on sandstone, the latter lying on laminated sandy shales. The lower layers of the Chinle are drab gray and greenish and the higher layers are red, brown, green, and gray. At various horizons are thin beds of sandstone 12 to 48 inches thick.

Unsuccessful attempts have been made to recover the gold from the Chinle formation. The shales swell and disintegrate readily in water. Mercury was detected when the shales were washed for gold. Both metals occur in small amount, assays of samples taken carefully ranged from 0.0006 to 0.0059 percent mercury and 6 to 12 cents gold per ton at Lees Ferry and 0.0040 to 0.0078 percent mercury and 5.6 to 10 cents gold at the Paria River. The gold was calculated at $20.67 an ounce. There is no indication of hydrothermal action and there are no veinlets of quartz or calcite, although quartz is abundant in the shales. The mercury is probably present partly as some oxidized mineral, perhaps calomel. The mercury and gold were probably transported to their present position by streams that carried the particles of clay and sand composing the Chinle shales.

1/ Lausen, Carl, The Occurrence of Minute Quantities of Mercury in the Chinle Shales at Lees Ferry, Arizona: Econ. Geol., vol. 31, 1936, pp. 610-617.

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Arkansas

In the Athens Plateau, Pike County, Ark. (fig. 3), there are three types of cinnabar occurrences, according to Branner:8/

1. Fracture fillings, including joints and bedding planes.
2. Dissemination in sandstone (comparatively rare).
3. Association with vein quartz (rare).

Most of the cinnabar deposits found up to 1932 occur in discontinuous and irregular areas of highly fractured sandstone. Also, regular joint systems and bedding planes in sandstone and shale frequently carry films of cinnabar. Free mercury was found as droplets in small, irregular cavities in sandstone, in quartz veins, and in sandstone fractures. Apparently, these were at one time filled with crystals of cinnabar, which were oxidized and reduced. (In 1934 and 1935 there were, respectively, 5 and 6 mines working in Arkansas producing a total of 433 flasks and 304 flasks.)

Stearn9/ describes the Parnell Hill mine of the Southwestern Quicksilver Co., Pike County, Ark., as an area underlain by sandstone and shale formations. The former consists of massive, medium to fine, even-grained, usually dark-gray beds ranging in thickness up to 16 feet. Generally, they are 2 to 3 feet thick with a fraction of an inch to several inches of shale between. The sandstone responds to weathering by shattering into angular blocks and fragments, which lie on the steep slopes of the ridges. Within the shale are sandstone lenses. The first showings of cinnabar to be discovered on Parnell Hill were in float rock on the south slope, which was traced to a massive shattered sandstone bed on the south flank of the hill. A trench dug in this bed showed crimson after rain. The mineral occurred only as fracture-filling material and at this point seemed to saturate the fractures. Exploration of the shattered zones uncovered much unsuspected ore. Further work proved that the ore-bearing solutions had permeated the fractures across the hill, and below the original trench another cut disclosed rich ore over 14 inches at the shale-sandstone contact. The cinnabar is generally coarsely crystalline, 1/4-inch crystals being common and 1/2-inch ores have been found. They are frequently perfect double rhombohedral twins. Minerals found with the cinnabar are kaolin, quartz, magnetite, and stibnite.

Reed and Hansell10/ give the following as being prospecting practice in the relatively new mercury district of Arkansas:

8/ Branner, George C., Cinnabar in Southwestern Arkansas: State Geological Survey, Little Rock, Ark., Inf. Circ. 2, 1932, 51 pp. ($2.)

9/ Stearn, Noel H., Mining and Furnacing Quicksilver Ore: Eng. and Min. Jour., vol. 134, 1933, pp. 122-124.

10/ Reed, J. C., and Hansell, J. M., Quicksilver Deposits near Little Missouri River, Southwest Arkansas: Tech. Pub. 612, Am. Inst. Min. and Met. Eng., 1935, 18 pp. (20 cents.)

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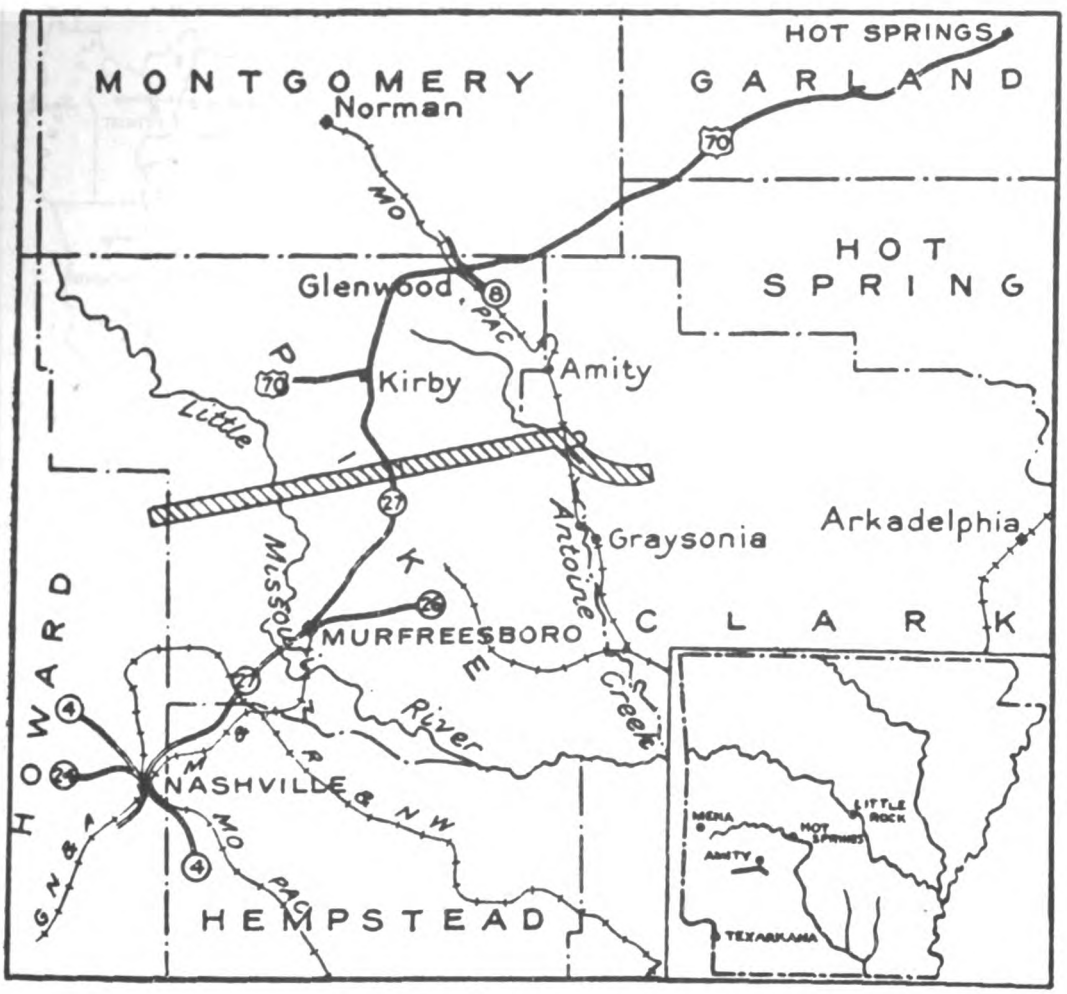

Figure 3.— Location and extent of the Arkansas mercury district.

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Figure 4.— The solid circles show locations of mercury deposits in California.

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Prospecting consisted in cutting into the sides of the hills toward places where mineralization was known to exist. The steep slope allowed faces 30 to 40 feet high to be exposed within horizontal distances of 50 to 75 feet. From these cuts it was possible to work laterally along the strike where desired. The advantage of this type of prospecting over sinking or drifting was in the better opportunity to study the mineralization. After the preliminary prospecting, it was possible to use the openings that showed the best mineralization as sites for sinking on the ore.

During prospecting, the mineralized rock was sorted and the waste discarded in the openings as the work progressed. In shaft mining all the rock is hoisted, dumped into bins, and then hand-sorted to a concentrate [ore] averaging about 20 pounds [1 percent] of metallic mercury to the ton. The proportion of waste rock to concentrate of this tenor [content] varies, but the average from combined prospecting and shaft mining on Parker Hill and Gap Ridge is estimated to be 6 tons of rock to 1 ton of ore of 20 pounds of mercury per ton.

California

In general, upon reading Schuette's paper[11/] on mercury occurrences, one concludes that the California deposits are closely related to the Franciscan series of sandstones and shales. Figure 4 shows their position in the State. At New Almaden, Santa Clara County, which has produced $75,000,000 of mercury, the footwall is serpentine and the hanging wall a clay gouge known as "alta", above which lies the Franciscan formation. The dip and strike of the orebodies followed that of the serpentine-sandstone contact. At New Idria, San Benito County, the second largest total producer in the United States, the ore lies near the contact between serpentine and Franciscan formation. At Oat Hill and Knoxville, Napa County, the former's deposits are fissure fillings of major fractures in sandstone beds which have been covered with basalt, also as impregnated zones in the more porous strata of the sandstone. In the Knoxville the ore is near the serpentine-sandstone-shale contact, but the latter lie unconformably upon the former. At Sulphur Bank, Lake County, a sulphur deposit covered the cinnabar, and sulphur and cinnabar are still being deposited by gas from hot springs. Rumbling and roaring sounds were audible at several vents. The ore is in the sandstone and shale, which is buried by sand and conglomerate. At Cloverdale, Sonoma County, the mercury is an irregular deposit and so are the workings. The ore, in general, is confined to a layer of chert under a gouge on a sandstone-chert contact. In Lake County, most of the oreshoots in the Great Western are enclosed on three sides (one wall and two ends) by serpentine, and those in the Helen and Great Eastern (Sonoma County) deposits are at the sandstone-serpentine contact. At the Oceanic deposit, San Luis Obispo County, in which are widespread indications of cinnabar,

11/ Schuette, C. N., Work cited (footnote 4).

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the ore-zone is 20 to 60 feet wide and has a hanging wall of thick gouge above and a mere slip in mud rock, the shells being changed to cinnabar and generally containing some native mercury.

Nevada

According to McCaskey,[12] cinnabar is more widely scattered in Nevada than was first thought, and prospecting has been fairly promising. The mineral is found in several counties, mostly in desolate country where fuel and water are scarce and costly to bring in. In 1936, 13 mines produced 190 flasks and in 1937, 11 mines yielded 211 flasks, despite the higher price for mercury.

Schuette[13] shows the occurrence of four mercury deposits in Nevada whose total annual production is only a twentieth of what it was in 1929. These may be stated as follows: Nevada group, ore under shale on a limestone-shale contact; Pershing, similar to the Nevada, also ore at a sandstone-limestone contact; Ruby group, ore at a sandstone-limestone contact, also in leached limestone; and B, ore in a volcanic breccia or tuff that has been intruded by igneous flows, the ore being not concentrated under a cap rock but spread out along the surface.

Interesting facts concerning the Ruby property are, first, the discovery was made by prospectors who had built a fire on the outcrop and noticed globules of mercury in the ash; second, they sank a shaft at the contact and exposed enough ore to sell the prospect; third, a retort was installed but the ore soon ran out; fourth, a geological study and tunnels revealed good, leached, ore-bearing limestone.

Mercury was discovered in 1912 in the Relief or Antelope Springs district, south end of the East Humboldt Range. (See fig. 5.) Some metal was produced up to 1919; the district was revived in 1927, and more mercury was recovered until 1931; at present there is little activity. Vanderburg[14] has covered the occurrence of mercury in Pershing County. In 1928 the Nevada quicksilver mine was one of the largest producers in the United States, and the Pershing Quicksilver Co. also was a fair producer. The former's mine was opened by a 450-foot shaft and the latter's by adits. The Pershing plant includes a Gould rotary furnace and a Herreshoff 8-hearth furnace. The rocks are mainly sedimentaries consisting of hard and dense limestone, sandstone, and shale. Cinnabar occurs in the limestone and sandstone at or near their contact with overlying shale. The ore bodies are lenses 5 to 40 feet wide, their boundaries being determined by the lowest grade material that can be mined profitably.

12/ McCaskey, H. D., Work cited (footnote 5).
13/ Schuette, C. N., Work cited (footnote 4).
14/ Vanderburg, William O., Reconaissance of Mining Districts in Pershing County, Nevada: Inf. Circ. 6902, U. S. Bureau of Mines, 1936, pp. 27-28.

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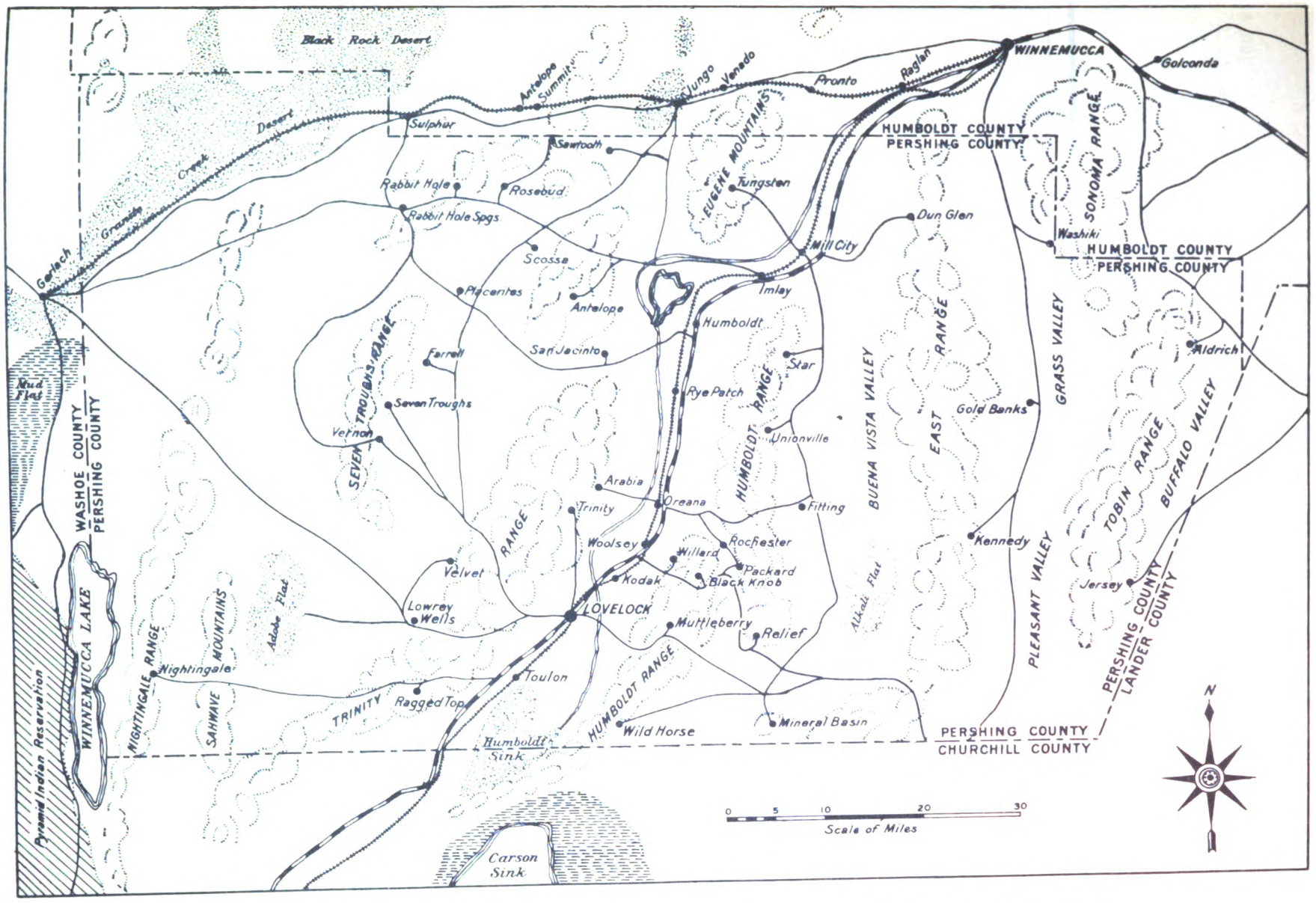

Figure 5.– Pershing County, Nevada. The mercury deposits are near Relief, east of Lovelock.

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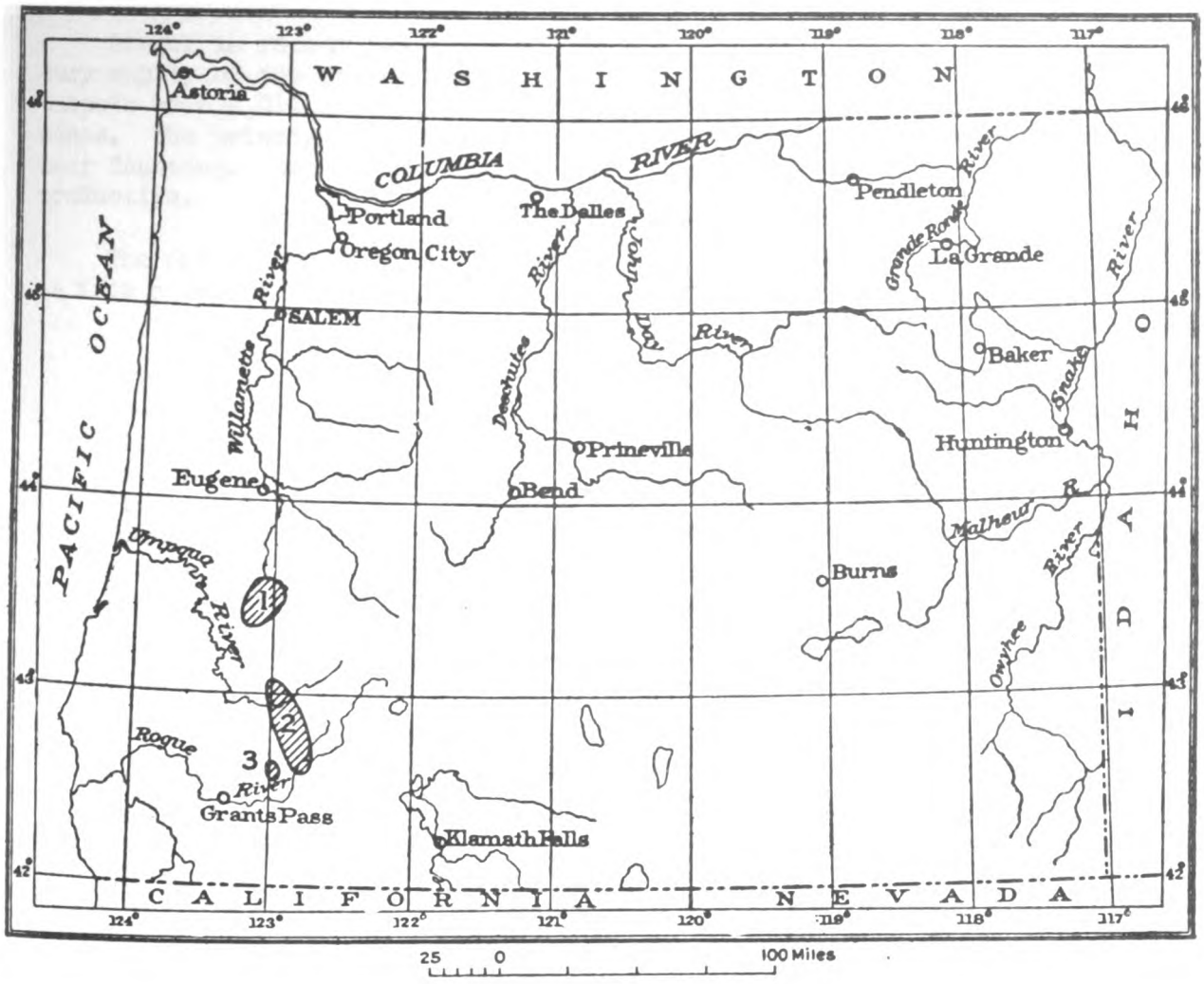

Figure 6.— Location of mercury deposits in southwest Oregon. 1, Blackbutte-Bonanza area; 2, Tiller-Trail area; 3, Meadows area.

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Vanderburg[14a] describes also the deposits in the Sodaville district of Mineral County. They lie on the northwest and southwest slopes of Cinnabar Mountain. Ore occurs in limestone, conglomerate, and silicified tuff. There has been a fair production and the possibilities are promising. Pipe and D retorts and a rotary furnace are being operated. Lessees are working some of the claims and producing mercury.

Oregon

Oregon in recent years has become an important contributor to the mercury supply of the United States. In 1931, 1935, and 1936 the respective outputs were 5,011, 3,456, and 4,126 flasks, from five, ten, and thirteen mines. The principal producers last year were in Jefferson, Lane, and Malheur Counties. Crook, Clackamas, Douglas, and Jackson Counties also are productive.

The following information, and figure 6, concerning mercury in Oregon, is from a report by Wells and Waters[15]:

> In western Oregon several deposits of quicksilver of sufficient size or richness to attract attention have been found along the western edge of the Cascade Mountains from Blackbutte, 15 miles south of Cottage Grove, to the Rogue River. As the eastern and southwestern parts of this quicksilver-bearing region lie within the Cascade and Klamath Mountains, they partake of the rugged nature of these ranges. The northwestern part lies within the confines of the Coast Range and has an open hilly topography. Though the region is sparsely settled, most of it is served by a system of good gravel roads. The more rugged parts, however, are almost uninhabited and are traversed by roads passable only in summer and by trails.
>
> The quicksilver deposits are characterized by a distinct type of hydrothermal alteration, by means of which the original rock has been bleached and softened, and its constituent minerals have been replaced partly by an intergrowth of microcrystalline silica and a carbonate that may be either calcite, ankerite, or siderite. The introduction of silica has commonly not extended beyond borders a fraction of an inch wide on either side of closely spaced small fractures that form a network through the rock mass. Oxidation of the siderite and pyrite along these fractures imparts to them a dark-brown color. Because of their silica content, they are more resistant than the rock mass to weathering and form a surface rubble that is a valuable guide to the prospector.

14a/ Vanderburg, William O., Reconaissance of Mining Districts in Mineral County, Nevada: Inf. Circ. 6941, U. S. Bureau of Mines, 1937, pp. 50-53.

15/ Wells, Francis G., and Waters, Aaron C., Quicksilver Deposits of Southwestern Oregon: U. S. Geol. Survey, Bull. 850, 1934, 58 pp. (30 cents.)

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The deposits are of two kinds - one in which the cinnabar occurs as small specks disseminated throughout the rock mass or as scattered threads and veinlets, and one in which the cinnabar and associated gangue minerals occur in small open fissures and gash veinlets or fault breccias. In deposits of the first type, the ore bodies are usually large but of low grade, averaging 4 to 6 pounds of mercury to the ton. In deposits of the second or vein-filling type, picked ore may contain as much as 4 percent [80 pounds] of quicksilver.

Cinnabar was first found in Oregon by the gold placer miners working the alluvial deposits in the Jackson district. The heavy purple-red sand that accumulated in their sluice boxes hindered amalgamation, but when it was known that the red sand was a quicksilver ore, attempts were made to recover the metal by distillation in crude retorts, and some of it was won in this way. ***

The deposits have a simpler mineralogy than is usual. *** The only other sulphides identified are marcasite and pyrite, of which marcasite is the more abundant. *** The most abundant gangue mineral is calcite, ***. Silica occurs commonly as quartz, ***.

Texas

In the Big Bend region of the Rio Grande, southwestern Texas, is the Terlingua district, which during the past 40 years has produced more than 125,000 flasks of mercury. Roughly, three-fourths of this output has come from the eastern part, which is only a few miles distant from the western part. The current production from four mines approximates 4,000 flasks a year. These properties increased their operations during 1935. See figure 7, reproduced from Minerals Yearbook.

According to Ross,16/ of United States Geological Survey, numerous prospects are scattered over the Terlingua district, which is about 14 miles long and 4 miles wide, but only at 10 places has there been any considerable development and rarely have there been more than three producers in any one year. Only two mines have depths of over 300 feet, and most of the workings are shallow.

16/ Ross, Clyde P., Progress Report on the Examination of the Terlingua Quicksilver District, Brewster County, Texas: Mineral Resources Circ. 7, Univ. of Texas, Bur. Econ. Geol., 1934, 4 pp. Preliminary Report on the Terlingua Quicksilver District, Brewster County, Texas: Univ. of Texas, Bull. 3401, 1935, pp. 558-568.

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Figure 7.— Location of the Terlingua and Mariscal mercury deposits, Brewster County, Texas.

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The mercury deposits are all similar, although they differ among themselves in various details. Most of the ore is cinnabar, but the black mineral metacinnabarite and native mercury occur in small quantities. Pyrite is rather widely distributed but is, in general, inconspicuous. Presumably, the red color of most of the mineralized rock of the district results from oxidation of the pyrite. The gangue is commonly a breccia of altered limestone and clay with ribs of coarsely crystalline calcite. Quartz and chalcedony are rare. Barite and fluorite occur locally. Bituminous matter exists in the ore in many places, but nowhere in abundance. It forms soft, globular masses, shiny black on fresh fracture, or, more commonly, impregnates the calcite and limestone, imparting a dirty yellow color to it.

Many of the principal oreshoots have been found in rather coarse-grained, easily soluble, jointed and fractured limestone under its cover of tough, nearly impervious clay shale. Much of this ore formed in or close to breccia zones along faults of the northeasterly trending system. At several places cinnabar is present in igneous rock, but it has not been developed.

More or less mercury is found so generally where structurally favorable places along the limestone-clay-shale contact have been exposed that it seems reasonable to hope that ore also is present at favorable places in parts of this contact not yet explored, as well as at places where similar contrasts in the permeability of the rocks exist at higher horizons, according to Ross. It is highly unlikely that mercury was deposited only in this part of Texas; therefore, prospecting outside of the Terlingua district is recommended.

Sampling and Testing

There is little need for close sampling and assaying of mercury ore at prospects and small mines. Samples fairly taken, crushed, and panned will reveal approximately the amount of cinnabar in the retort feed and discharge. A number of methods for assaying mercury ore are in use. The method[17] of the United States Bureau of Mines is considered to be the simplest and most rapid available, but for a small mine the operators should resort to panning and should send an occasional sample to a regular assay firm if some problem arises. Sampling and assaying are rendered more or less unsatisfactory if the cinnabar is distributed irregularly. Cinnabar is brittle and breaks away easily from the gangue. Panning is made simpler by its specific gravity of 8 and that of 2.6 for silica and limestone.

17/ Bouton, C. M., and Duschak, L. H., The Determination of Mercury: Tech. Paper 227, Bureau of Mines, 1920, 44 pp. (10 cents.) This report also contains a bibliography of analytical methods for mercury.

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The Bouton-Duschak test is known as the "glass-tube method", and consists in separating the mercury by distillation in a closed tube, dissolving it in nitric acid, and titrating with potassium thiocyanate.

Davis[18] briefly gives practical methods for the estimation of mercury in ore, following these by assay methods. He says that the prospector familiar with mercury minerals is able to recognize high- or medium-grade mercury ore and can make a guess at its metal content. It is best to break the ore to expose a fresh surface and note the red sulphide, or the gray, brown, or yellow chloride, if present. A fairly close estimate of a cinnabar content of an ore is obtained by panning. Some panners become very proficient in the art - prospectors, miners, and plant operators - and can work accordingly.

MINING METHODS

Mercury ore may occur mainly as a surface deposit or persist in depth and be adaptable to open-pit or underground methods of mining. Following are some examples:

Arkansas

At the Parnell Hill mine, Pike County, Ark., according to Stearn,[19] the ore was developed by means of three cuts driven directly into the hill from an 18-inch-gage track laid along the hillside. These cuts crossed the shale-sandstone contact and encountered the cinnabar mineralization. At two of these cuts mining consists of ordinary quarrying accompanied by careful hand-picking to separate the rich ore, which is trammed to the treatment plant. At the third cut, open work was stopped and drifts were run thereoff along the contact. At a fourth point, blasting an unmineralized fracture disclosed a brecciated zone richly mineralized. Here, drifting, crosscutting, winzing, and stoping is done. The shale requires timbering but the sandstone does not.

Branner's report[20] on Arkansas mercury deposits is well illustrated with photographs of early mining operations - surface prospecting, starting a drift in sandstone, starting an open cut in sandstone, a large open cut, drifts or tunnels in sandstone, sorting in open cut, specimens of ore, photomicrography of ore, and furnace plants.

18/ Davis, C. W., Distillation-Amalgamation Methods for the Determination of Mercury in Ores: Inf. Circ. 6202, Bureau of Mines, 1929, 8 pp. (Out of print.)

19/ Stearn, Noel H., Work cited (footnote 9).

20/ Branner, George C., Work cited (footnote 8).

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California

At the Sulphur Bank Mine, Lake County, Calif., the deposit covered about 100 acres to an average depth of 5 feet. The ore consists of cinnabar disseminated throughout principally a soft, altered basalt, according to Bradley.[21] Mining is done by open-cut with two 1-cubic-yard shovels, each operated by a 75-horsepower Diesel engine. The ore is loaded by the shovels into motortrucks of 8 cubic yards capacity. The trucks haul the ore about a quarter mile to a bin at the lower terminal of an incline tram to the plant. The ore is dumped directly into the bin through a sloping grizzly of 70-pound rails with 9-inch openings. Sorting is done later. In one month 9,000 tons of dry ore have been mined as described.

At New Idria, San Benito County, Calif., according to Moorehead[22], the ore zone occurs near a contact between serpentine and shales and sandstone in various stages of alteration. The average dip of the deposit is 55°. In the ore zone the cinnabar occurs in seams in stockworks, in fissures, and as impregnations in sandstone. The mine was developed by a series of adits from the mountainside, also by a shaft below the lowest adit. Both underground and open-cut mining are done. The latter can be done to the 300-foot-level adit, but an enormous tonnage of waste has been and will have to be removed. It is glory-holed to this level and carried outside by belt conveyor. Power shovels of 3/8- and 1-yard capacity and 5 1/4- and 6 1/4-ton motor trucks are used in mining the ore, which is screened and sorted, as described later. Underground mining is done by open-stoping or square-setting. Stripping, mining, and hauling costs 58 cents per ton; underground mining costs 28 cents per ton.

Oregon

Wells and Waters[23] give brief descriptions of the methods of mining in Oregon, as follows:

The Blackbutte mine, which is at an elevation of 1,650 feet in Lane County, was developed by six levels connected by raises and connected with the surface by a series of adits driven from the northeast side of the butte. In 1930 the workings had opened ore through a vertical range of about 1,250 feet and along the strike for 1,200 feet. The output of ore was 100 tons a day, and a grade of 3 1/2 pounds per ton could be worked profitably.

21/ Bradley, Worthen, Method and Cost of Recovering Quicksilver from Low-grade Ore at the Reduction Plant of the Sulphur Bank Syndicate, Clearlake, Calif.: Inf. Circ. 6429, Bureau of Mines, 1931, 7 pp., 5 figs. (Out of print.)

22/ Moorehead, W. R., Methods and Costs of Mining Quicksilver at the New Idria Mine, San Benito County, Calif.: Inf. Circ. 6462, Bureau of Mines, 1931, 14 pp., 8 figs.

23/ Wells, Francis G., and Waters, Aaron C., Work cited (footnote 15).

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The Elkhead mine, which is at about 1,000 feet in Douglas County, was opened by two glory holes and several adits.

In the Butte section of the Nonpareil-Bonanza area of Douglas County are a number of abandoned prospects opened by tunnels.

The Nonpareil mine has been developed mainly by adits, which are at an elevation of 900 to 1,100 feet. The area prospected extends over 3,600 feet. The ore occurs in beds of tuffaceous sandstone as irregular shoots. The Bonanza mine also was opened by adits and by a glory hole.

More than 50 miles separate the Nonpareil-Bonanza area from the Meadows area, which is south in Jackson County about 20 miles northeast of Grants Pass and 17 miles north of Medford. About midway is the Tiller-Trail district, which has several prospects and a small production of mercury. Evans Creek flows through the Meadows area, in which is the Dave Force mine at an elevation of 1,900 feet. It has been opened by adits, and the ore consists of small crustified veinlets of cinnabar with calcite and quartz gangue, and chalcedony breccia containing cinnabar. The War Eagle mine is opened by adit, drift, and winze. It is estimated that the ore yielded 22 pounds of mercury per ton. The ore consists of a fault breccia in chalcedony in a little silicified schist cemented by marcasite, in which is the cinnabar.

TREATMENT

Mercury is recovered in the United States from a number of mines scattered over a large area; the metal lends itself to treatment in small retorts that can be erected at relatively little cost; therefore, almost every mine has its own refinery. Many retorts are built, produce a few flasks of metal, and are abandoned when the small reserves in the mines are exhausted, the cost of extracting the mercury is high, or some other difficulty interferes. Consequently, the extraction of mercury from ores, its shipment, and handling have been highly individualized. In the past many small operators have been careless in cleaning containers and have known too little about the proper material for sealing the flasks. These conditions have been responsible in large measure for the fact that some domestic mercury has not been as pure as it should be and that, as a result, some consumers of mercury prefer the foreign product (according to Furness and Meyer).[24]

Sorting

Careful and systematic sorting of an ore may mean the difference between a non-paying and a profitable mine. Many ores lend themselves to this treatment, gold ores in particular. Sorting may be done partly underground and partly on the surface. The coarse discard should be sampled and panned or assayed occasionally to determine how efficiently the sorting

24/ Furness, J. W., and Meyer, H. M., Mercury: A chapter (pp. 437-463) in Minerals Yearbook 1935, Bureau of Mines, 1935, 1,293 pp.

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is being done. At most mercury mines some barren or poor rock, particularly wall rock, is thrown out by the crusher attendant. Schuette[25] states that some of the sorting he witnessed in Texas may not be worth while, whereas the discarding of waste at the crusher can be made to pay. One important feature to remember while sorting mercury ore is the brittleness of cinnabar. The mineral breaks easily, and the fines made in mining and general handling are generally high grade. Therefore, none of such material should be lost.

A paper[26] of the American Institute of Mining and Metallurgical Engineers bearing the general title "Quicksilver Industry in 1929", includes two papers. These are mainly for large operators, but Duschak says this:

> There is a very apparent need for economical methods during the development of a property or where operations are necessarily on a small scale. Hand sorting and retorting have been the chief reliance in this connection. However, this practice is successful only where a relatively high grade product, say 5 to 10 percent Hg, can be economically produced by sorting. When this is not possible a small furnace plant or a small flotation plant and battery of retorts offer the best solution.

California. - Sorting mercury ore at the Sulphur Bank mine, Lake County Calif., is described by Bradley[27]. The ore consists of grains of cinnabar finely disseminated throughout a gangue composed principally of altered basalt, but distribution through the basalt is not uniform and large boulders of partly altered basalt are barren. The ore is fed to a trommel with 1-inch holes and the oversize passes to a picking belt, where 60 percent of the feed is rejected as waste. Water sprays are used also. The cinnabar occurs mostly in the fines. During one month, 9,000 tons of dry ore assaying 4 1/2 pounds of mercury per ton was mined. Of this, 5,400 tons of 1 1/2-pound waste was rejected. The 3,600 tons of ore sorted and screened contained 9 pounds per ton. Screening, sorting, and crushing cost 83 1/2 cents per ton of ore treated, which in that month was 1,290 tons. Based on the original rock mined, the cost would be 7 cents per ton.

According to Moorehead,[28] the New Idria workings produced 750 tons of low-grade material a day and a tenth of this was discarded after having been screened and hand-sorted. The cinnabar occurs in seams in stockworks,

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25/ Schuette, C. N., Work cited (footnote 4).
26/ Duschak, L. H., Improvements in the Metallurgy of Quicksilver (pp. 3-18); Maier, Charles G., and 12 others, The Present Status of Our Quicksilver Industry (pp. 19-32, and discussion, pp. 33-37): Am. Inst. Min. and Met. Eng., Tech. Pub. 264, 1929, 37 pp. (40 cents.)
27/ Bradley, Worthen, Work cited (footnote 21).
28/ Moorehead, W. R., Work cited (footnote 22).

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in fissures, and as impregnations in sandstone. Hanging-wall waste is removed by the glory hole and dumped outside. All ore mined underground went direct to the furnace without sorting or screening. Of the quarry ore, 600 tons a day, sent to the screening and sorting plant, 60 percent was discarded as waste. There was preliminary sorting on one belt conveyor followed by trommeling and sorting of the coarse ore on another belt. Screening and sorting of quarry ore cost 15 cents per ton on 21,516 dry tons mined in one month.

Oregon. - At the Opalite mine of the Mercury Mining Syndicate, southeastern Oregon, according to Schuette,29/ the siliceous cinnabar-bearing rock was dumped onto a 2-inch grizzly and the oversize was sorted on a platform before it was reduced to 1 inch in a jaw-crusher. The bin for oversize has five chutes opening on the sorting floor, and there was a small waste bin at each end and under the floor. Two men fed the crusher, picked out waste, and trammed it to the dump. Three to four percent was picked out of the furnace feed.

Texas. - Duschak and Schuette30/ describe and show how mercury ore at the Big Bend mine, Brewster County, Tex., was sorted: All minus 3-inch rock passes through a gable grizzly to an ore bin; the oversize falls onto a sorting platform at each side, the ore being thrown into the bin with the undersize and the rock into waste bins. This is a convenient and simple arrangement. Half of the mine product was discarded. The cost, based on the original tonnage mined per day (80), was 8 to 9 cents per ton, or 16 to 18 cents based on the 40 tons of sorted ore. The reject carried little mercury. This is a limestone ore that is adapted to close sorting.

Retorting

"How fine should ore be broken before it is fed to retorts?" may be asked. This depends upon the texture of the ore and the manner of mineralization, but the range of size at a number of plants is 3/4 inch to 2 inches, the latter being the largest, although 3-inch size is fed to large rotary furnaces.

According to Duschak and Schuette,31/ the retort furnace was the earliest device used for the extraction for mercury from its ore. The retort was widely used in China. In the United States, the retort has been used for two purposes - for the treatment of selected ore and for the recovery of mercury from intermediate products of treatment plants, such as mercurial soot and flotation concentrates. Also, it has been common practice to use the retort furnace in the early stages of development of a prospect and at small mines. Schuette, who devotes little space to retorts in his excellent bulletin,32/ states that they are used more now (1930) than 10 years ago, both

29/ Schuette, C. N., Work cited (footnote 4).
30/ Duschak, L. H., and Schuette, C. N., Work cited (footnote 3).
31/ Duschak, L. H., and Schuette, C. N., Work cited (footnote 3).
32/ Schuette, C. N., Quicksilver: Bull. 335, Bureau of Mines, 1931. 168 pp. (Out of print.)

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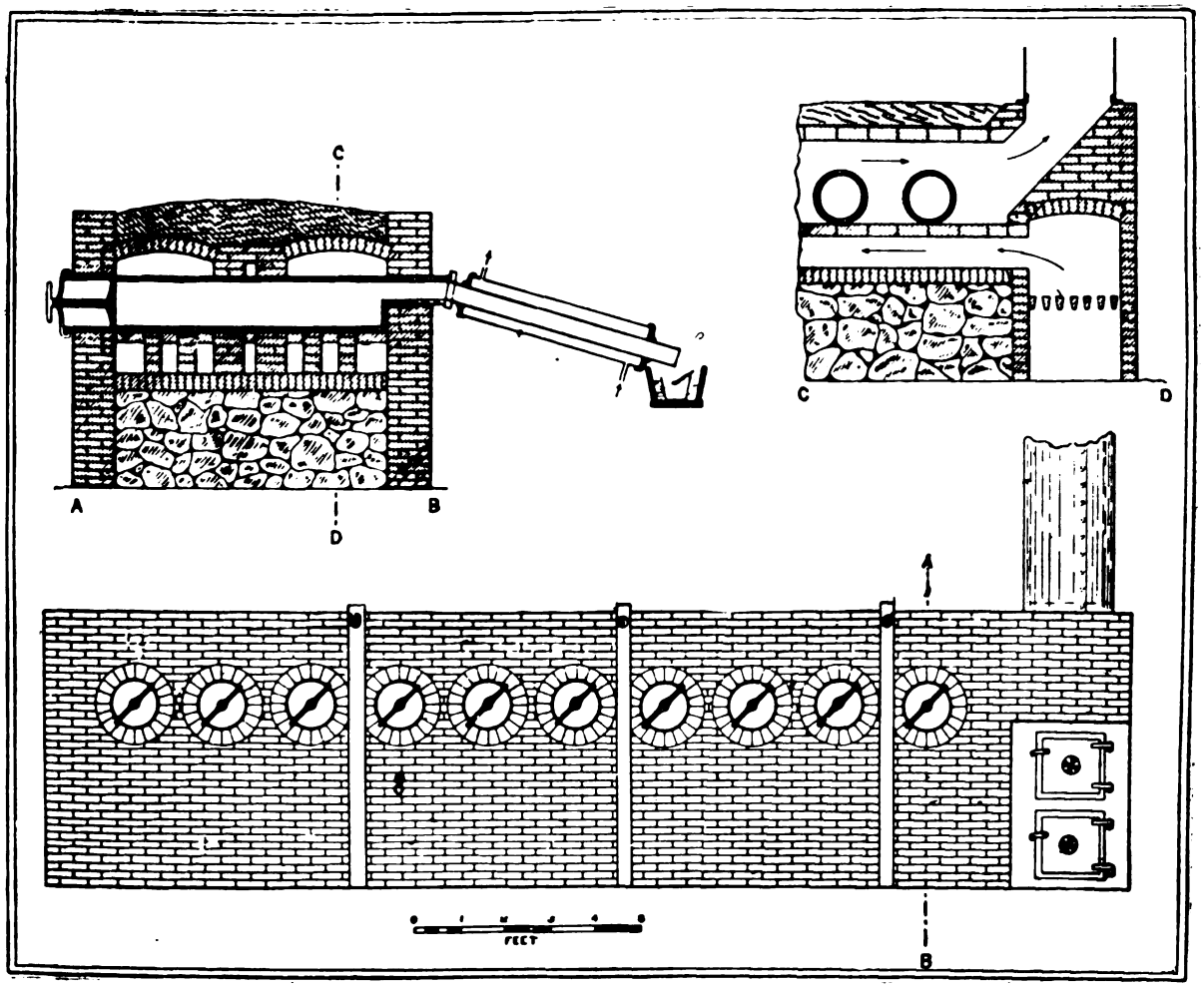

Figure 8.— Details of setting pipe retorts and condenser.

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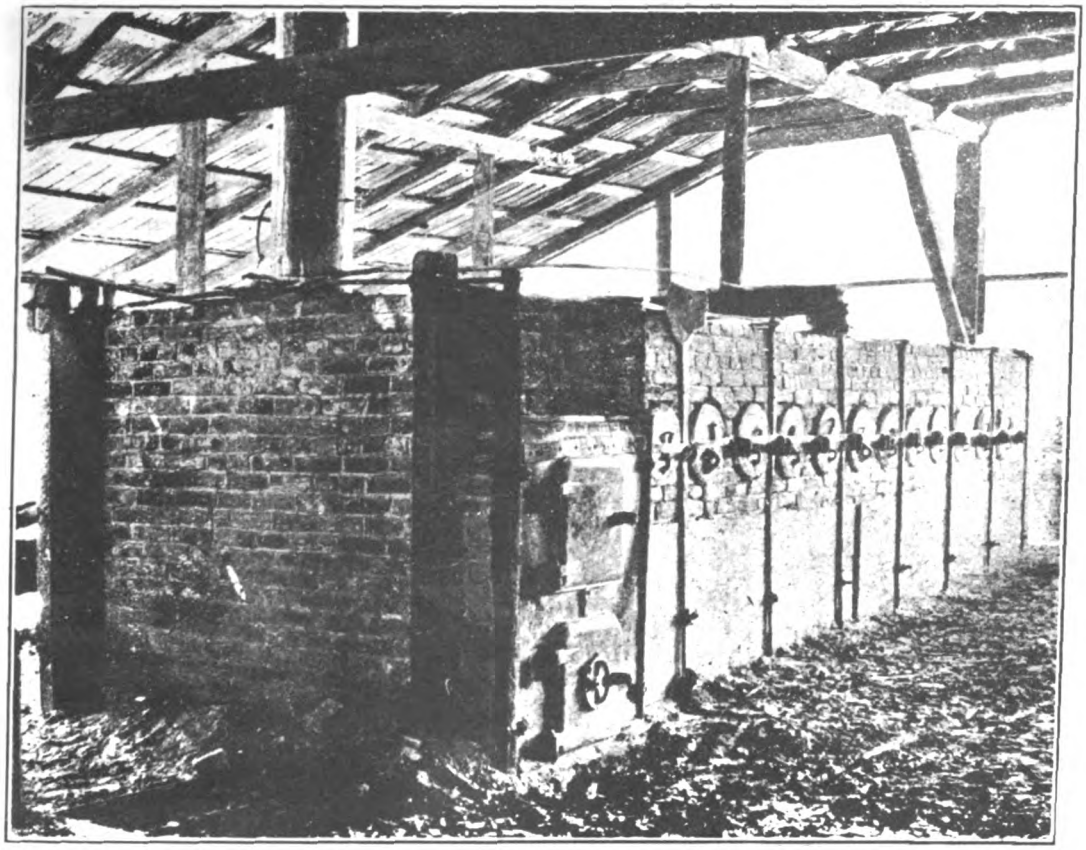

Figure 9.— Battery of 12 pipe retorts.

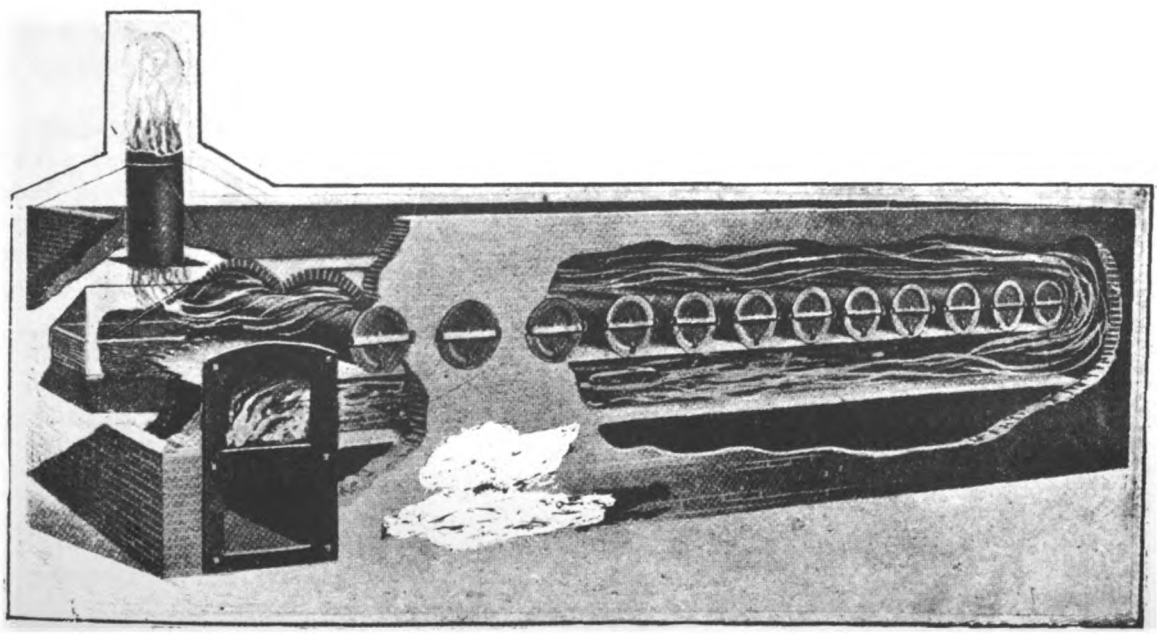

Figure 10.— Phantom view of battery of 12 retorts, revealing the circulation of heat.

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by prospectors and as an adjunct to furnace plants. He disputes the need of retorts as a necessary auxiliary to rotary-furnace practice.

The following information on retorts is taken partly from Duschak and Schuette's bulletin[33] and partly from Bradley's report[34] on California:

Pipe Retorts

Types. - Retorts are made in two forms - pipe retorts and D retorts - the difference being merely one of shape and size. They are generally of cast iron. The pipe retort consists of circular iron pipes, 8 to 12 inches in diameter, arranged in banks or groups containing up to 12 pipes. The D type are of larger capacity and have a cross-section like the letter D but with the straight side laid flat, thus: ⌓. They are mounted singly or several of them together in a furnace, so arranged that the hot gases from the firebox will circulate around all sides of the retort. It is common practice to protect the retort by firebrick or fireclay tile so that the flame from the firebox will not impinge directly upon the cast iron. The retort should be so supported that it is subject to little mechanical strain.

(In a manner, the D-retort resembles the retort used in gasworks for making gas from coal, but of course the dimensions, material, and temperatures differ. In each case the retort is charged, the door is luted with clay and clamped at one end, the fire is urged, distillation and vaporization proceed, condensation follows, and the retort is emptied and recharged.)

Practice. - Figure 8, reproduced from Bradley's Bulletin,[35] which was reproduced from Forstner's bulletin,[36] shows at the top left a profile of the end retort and condenser of a battery of 10 pipe retorts, at the top right a part of the firebox and flue system, and at the bottom the front of the battery. Figure 9 shows a battery of 12 pipe retorts.

Ten-inch pipe retorts are 9 feet in length and the 12-inch retorts are 7 feet, the capacity varying from nearly 5 to 5 1/2 cubic feet. The condenser pipes are 3 inches in diameter and 8 feet long and are set into the retort pipes with rust joints. The retorts are charged with a large scoop provided with a long handle, although a man adept with a shovel should be able to do this with little spilling; men charging gasworks retorts can do so.

33/ Duschak, L. H., and Schuette, C. N., Work cited (footnote 3).
34/ Bradley, Walter W., Quicksilver Resources of California: California State Mining Bureau (now Division of Mines) Bull. 78, 1918, 389 pp. ($1.50 plus 35 cents postage.)
35/ Bradley, Water W., Work cited (footnote 34).
36/ Forstner, William, The Quicksilver Resources of California: California State Mining Review (now Division of Mines), Bull. 27, 1903, 273 pp. (Out of print.)

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The retort is not completely filled with ore, consequently a supply of free oxygen remains to unite with the sulphur driven off and thus prevents its recombining with the vaporized mercury. Air is sometimes admitted to the retort by means of a special 1-inch pipe fitted into the door and extending to the back, the air escaping outside through another pipe from just behind the door. Air is circulated by a fan or other supply. If much sulphur is present in the ore, lime must be added to take care of it. The mercury vapor or gas stream from the individual pipes is collected in a manifold leading to the condenser.

With regard to condensing the mercury vapor, the condenser pipes should be set at an angle and discharge into a trough of water, as in figure 8. If water is available, it may be sprayed onto the pipes or passed through a water jacket surrounding the condenser pipe, the incoming water entering at the lower end and leaving at the top. The most effective arrangement depends upon local conditions, and various systems have been more or less successful.

Johnson-McKay retort. - Figure 10 is a phantom review of a battery of a dozen Johnson-McKay pipe retorts made by Joshua Hendy Iron Works, San Francisco, Calif. It reveals the firebox, circulation of flame and hot gas, the stack, and how the retorts are supported and closed. The front and back ends of the pipes receive most of the heat.

Fewer pipes may be built in, if desired, and a 10-inch size is available, but the standard 12-inch is considered better. If 12 pipes are installed and the calcining period is 12 hours, one pipe would be discharged and recharged every hour. But the period of roasting depends upon the character of the ore, the heat maintained, and the general attention given. The standard size of furnace should treat 3 to 5 tons of ore daily, but 7 tons have been calcined in such a furnace. The consumption of wood fuel is 1 1/4 to 1 1/2 cords per day. If 10-inch retorts are used, 12 of them will handle 1 1/2 to 2 tons in 24 hours, burning 1 to 1 1/2 cords of wood. Fuel-oil might be available in some districts.

The iron work for a battery of 12-inch retorts may cost $1,000 and the complete furnace around $2,000; but such costs vary with local conditions, including the supply of brick and building material. A simple shed is all that is needed as a cover to the furnace.

Ironwork for a Johnson-McKay mercury retort as furnished by the Joshua Hendy Iron Works consists of the following, according to that firm's instruction sheet:

12 cast-iron retort pipes 12 inches in diameter and 6 feet long.
15 inside covers and 15 outside covers for pipes (this allows three spares), with lock bars and wedges.
12 cast-iron condenser pipes each 8 feet long.
1 cast-iron stack plate.

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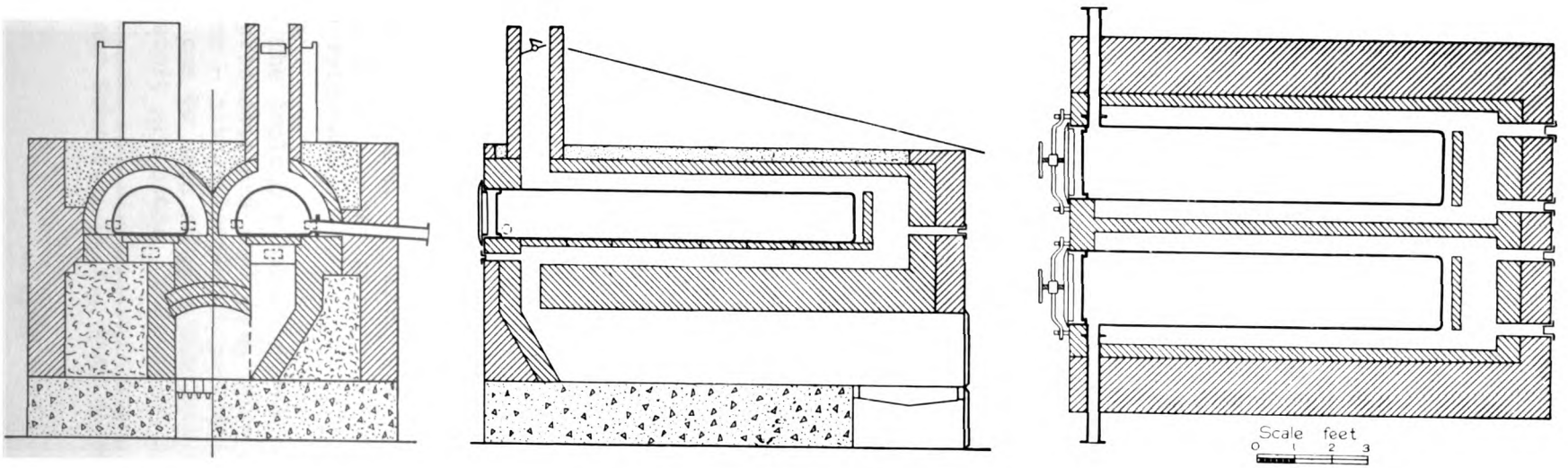

Figure 11.— Details of setting D retorts.

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1 smokestack 20 feet long.
6 full-length structural-steel buckstays for firebox and ends of retort and 12 short structural steel buckstays for sides of retort, together with necessary buckstay rods.
2 dampers.
1 steel apron-plate placed below the retort pipes to protect the brickwork.
1 charger scoop.
1 hoe for retort pipes and 1 hoe for condenser pipes.

When a retort is to be fired with wood or coal, the firm also furnishes one fire-front with anchor bolts. The oil-fired retort does not require a fire-front. The total weight of ironwork is approximately 11,000 pounds as packed for domestic shipment. Drawings and a bill of material for the retort are furnished, from which brick and other material can be ordered and the retort constructed.

Two covers are furnished with each pipe; the inner cover in luted with clay and the outer cover wedged in placed, thus preventing escape of fumes with consequent danger to workmen. As the cinnabar becomes heated the mercury volatilizes, passes into the condenser pipe, where it is condensed and runs into a wooden trough, which is filled with water to prevent escape of any uncondensed vapor.

D Retorts

At least two D retorts should be employed, even at a small mine. Figure 11 shows sections of a two-D-retort metallation, as given by Duschak and Schuette.37/ They are supported throughout their length by fireclay tile. A stack is provided for each, so that by means of a damper the heat of each retort can be closely controlled.

The flame from the firebox passes back through a central flue, thence through passages in the end wall to the flues under the retorts. The use of fireclay tile to protect the closed end of the retort from the sweep of the hot gas adds to the life of the retort.

This installation would probably treat 1/2 to 3/4 ton or more of ore in 24 hours, burning 1/2 to 3/4 cord of wood. If well built and properly handled, such retorts may last two years. A sheet-iron hood should be built above the charge doors to carry off dust, hot air, and any fume that may be present when discharging the retorts.

Gould retort. - The Gould D retort has been especially designed to treat small tonnages from prospects and soot from large furnace operations. It is made of gray cast iron - either left-hand or right-hand. In a single pipe setting, either type can be used singly, but in a two-pipe bank, one left-hand and one right-hand retort are used. A complete single retort and smokestack

37/ Duschak, L. H., and Schuette, C. N., Work cited (footnote 3).

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weigh 3,180 pounds and cost $366. in San Francisco. This retort is generally fired with wood, but oil may be used, the extra equipment therefor costing $290 in San Francisco. If fine ore or other material is to be calcined, charging pans should be used. Three of these cost $27.50. Complete plans and instructions are furnished with each order, including the amount of brick, lumber, and other material needed. The capacity of this retort varies with the character of the material treated, but in general, two 12-hour charges of 700 to 1,000 pounds can be treated and, if the retort is operated continuously, three charges of 400 to 500 pounds per 8 hours can be calcined per day.

Pacific Foundry Retort. - The D retort of the Pacific Foundry Co., San Francisco, Calif., is a casting with a body 12 by 20 inches by 8 feet and with a head an additional 12 inches. It is made right-hand and left-hand. Figure 12 shows a complete retort, in this case for right-hand setting. It is housed in a brick setting 11 feet 8 inches long, 5 feet 6-1/2 inches wide, and 7 feet 4 inches high. This provides for a combustion chamber and ashpit suitable for burning cord wood. The retort is placed above the chamber and rests on fireclay tile 3 inches thick. The chamber is on the end opposite the retort head. The stack, which is 10 inches in diameter, is directly over the retort head. The relation of the combustion chamber, retort, and stack provides for a three-pass flow of combustion gases in a manner that avoids over-heating the retort.

Mercury ore is placed in three pans, each 18 by 32 by 4-1/4 inches and holding 200 pounds; the total charge, therefore, is 600 pounds. The number of charges will vary with the characteristics of the ore, but is one to three per 24 hours. Approximately half a cord of wood is burned in this period, but the retort setting can be supplied for oil fuel.

The price of the complete retort shown in Figure 12 is $240, f.o.b. San Francisco. When made of close-grained gray iron the weight is 2,320 pounds. When made of "Pyrocast", a nickel-chrome-iron heat-resisting alloy, the cost is $385.

Additional requirements for a complete installation are:

Steel tie-rods.
Buckstays and wall beams.
Cast-iron stack base.
Cast-iron firedoor with liner.
Steel firedoor frame with anchor bolts.
Steel stack with damper.
Group of 4- and 6-inch cast-iron pipe for condensing the mercury.
Fireclay brick and tile.
Common red brick.
Bonding materials.

The foregoing information was supplied by George E. Connolly, mechanical engineer for the Pacific Foundry Co.

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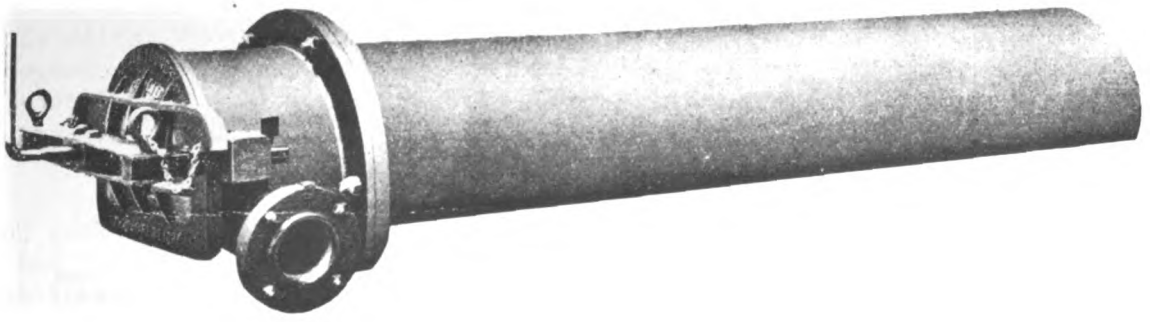

Figure 12.— Pacific Foundry Co. D retort for mercury ore, 12 by 20 inches by 9 feet.

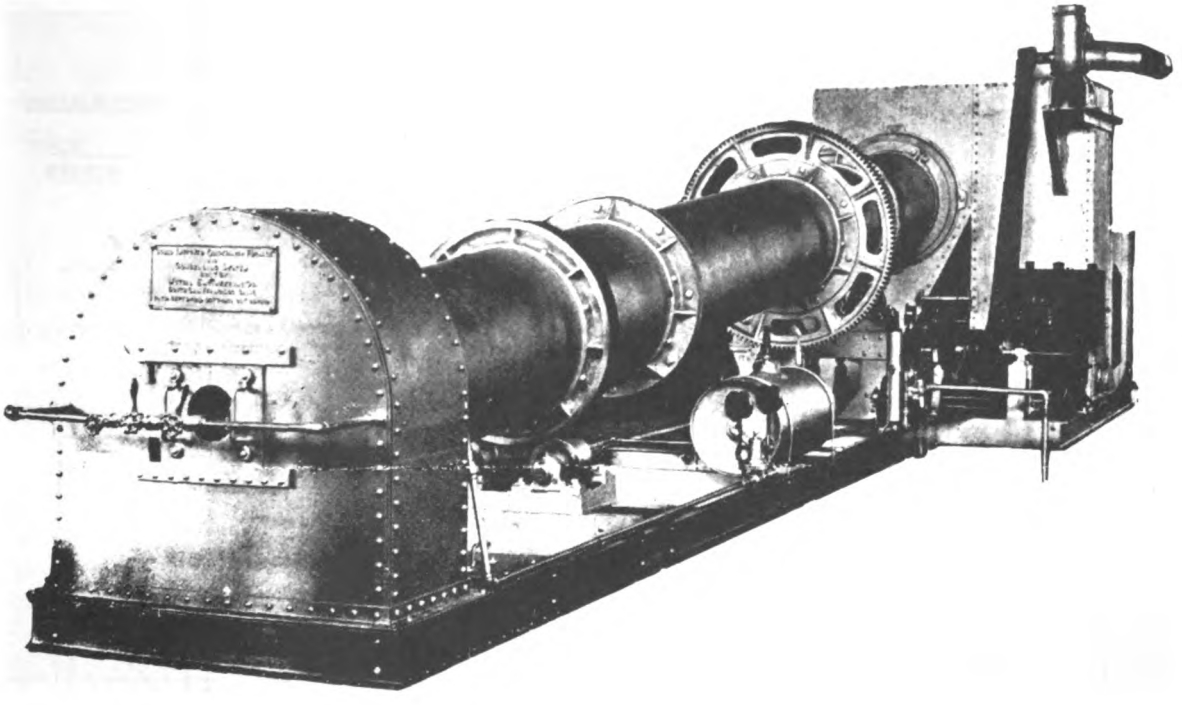

Figure 13.— Gould 2 by 24-foot rotary kiln and condenser of 12 to 20 tons capacity in 24 hours.

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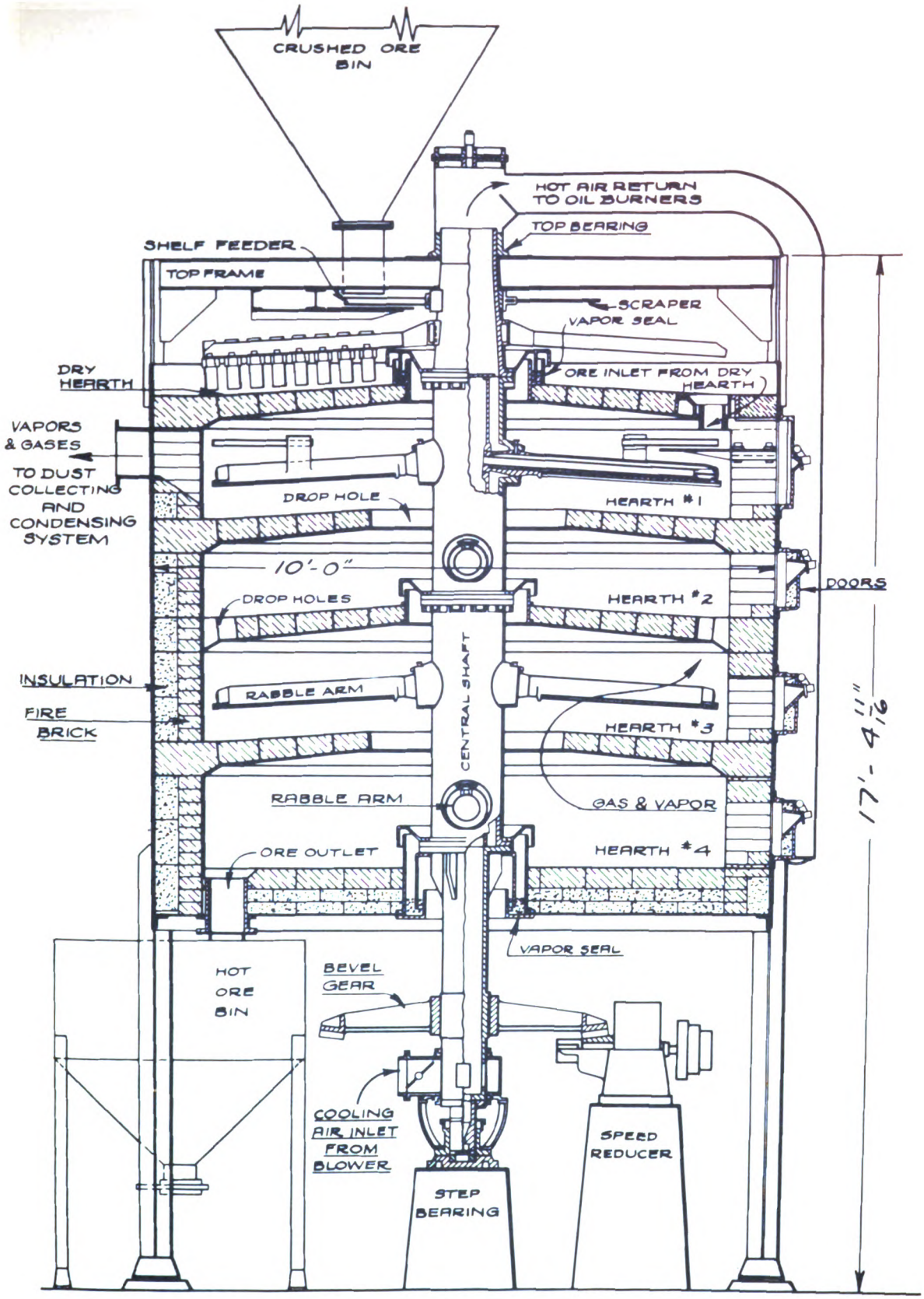

Figure 14.– 20-ton Nichols Herreshoff mercury furnace.

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Rotary Furnace

For a mine capable of producing up to 20 tons of mercury ore in 24 hours, one of the Gould semiportable rotary furnaces and condensers is suitable. This equipment is self-contained on a single bed-frame and costs $6,859 to $7,480 in San Francisco. Its furnace is 24 inches in diameter and 24 feet in length and the daily capacity, depending on the ore, is 12 to 20 tons. It is fired with oil, requires little water, is portable, erection costs are low, it makes a high recovery, and may treat ore at 75 cents to $1 per ton. Power is supplied by a 15-horsepower gasoline engine. Figure 13 shows this equipment.

Suitable similar furnaces for smaller or larger mines are the 18-inch by 16-foot size that treats 8 to 12 tons per day and the 36-inch by 40-foot size that handles 25 to 50 tons per day.

For large mines there are still larger sizes. The labor costs on the large furnaces naturally are lower than on the small ones.

Another manufacturer of the rotary-type furnace is the Cottrell Engineering Co., Los Angeles, California. Its countercurrent kiln with metal condenser and dust collector on one frame is a complete unit. A number are reported to be in operation.

The Pacific Foundry Co., previously referred to, makes the Nichols Herreshoff multiple-hearth furnace with one drying hearth at the top and several calcining hearths. Fuel oil is used. The furnace has a capacity of 20 tons and more a day and will handle wet or dry ores in size from 200-mesh to 1 1/4-inch diameter. The ore passes from one hearth to another, being rabbled or stirred by air-cooled rotating arms to which rakes are attached. Dusting is reported to be low. Young[38] gives details of the operation of this furnace at the present Great Western mine by the Bradley Mining Co. near Middletown, Calif. The cost of furnacing varied from $1.53 to $2.75 per ton of ore, which yielded 7.1 to 14.5 pounds of mercury. The total cost of mining, retorting, and general expenses was as low as $28.35 and as high as $50.57 per flask. The selling cost was $3.60 per flask additional. Figure 14 reveals details of the Nichols Herreshoff furnace.

Examples of Retorting

In Arkansas. - According to Brannor[39], the Arkansas Quicksilver Co., Pike County, Ark., had a two-tube, type D, Gould retort. In 1932 it was calcining 3,000 pounds of ore in 24 hours, recovering 40 to 60 pounds of mercury therefrom. The metal, by analysis, contained 99.99+ percent mercury, 0.001 percent iron, and not over 0.001 percent of other heavy metals.

38/ Young, G. J. A., California Quicksilver Plant: Eng. and Min. Jour., May 1932.

39/ Branner, George C., Work cited (footnote 8).

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The Southwestern Quicksilver Co. erected a three-tube D retort late in 1931 and in 25 runs treated nearly 20 tons of ore averaging 1.73 percent mercury. The retort charges weighed 800 pounds.

In September 1936, according to information supplied Branner[40] by a visiting engineer, the Mercury Mining Co. was operating a 10-ton-capacity Gould rotary furnace under a rental agreement with the Southwestern Quicksilver Co. A 32-gravity fuel-oil is burned. In another section, the Mercury Mining Co. has a 12-pipe Johnson-McKay furnace burning 4-foot wood. Nearby, the McHolmes Mining Co. had a homemade furnace of ten 12-inch pipes 6 1/2 feet long, having a daily capacity of 2 tons of ore. Five more pipes were being added. Four-foot wood is burned.

In California. - At the Sulphur Bank mine, previously mentioned, a high-grade condenser mud and high-grade flotation concentrates are produced by the rotary-kiln treatment of the ore. After being dried, these products are retorted in three standard D retorts. These are 12 by 18 inches by 8 feet and the retort firebox is 24 inches square and 9 feet long. A charge weighs 300 pounds and is left in the retort for 24 hours. Retort residues mixed with water are used to seal the retort doors. Each retort is equipped with a Ray oil-burner that has independent air and oil control. At the front of each retort, over the door, is a hood through which the retort gases can be drawn by means of a fan when the door is opened. The condenser consists of standard 4-inch pipe surrounded by a zinc-coated (galvanized) iron water-jacket about 12 inches in diameter with a 1-inch water inlet and outlet. The mercury flows to a bucket, after which it is cleaned with water in a 16- by 10- by 10-inch-partitioned cell and finally bottled. Retorting costs around 18 cents per ton of dry ore treated.

In the California Journal of Mines and Geology for October 1935, a quarterly chapter of the State mineralogist's Report 31, San Francisco, Herbert A. Franke describes the mines and mineral resources of San Luis Obispo County, Calif. This area includes a number of small and medium-size mercury deposits and treatment plants. In 1927, Louis I. Rossi, of Paso Robles, Calif., developed an inexpensive and efficient retort, which is now reported to be giving satisfaction at a number of small mines. The following note has been abstracted from Franke's report:

> Figure 15 shows a unit of two pipes having a daily capacity of a 1/2 ton. The 2-pipe retort is a unit complete with firebox. The pipes are cast from heat-resistant alloy, 5/8 inch thick, 74 inches long, and 10-inch inside diameter. Discarded Johnson-McKay retorts are often used, opening one end for the lower discharge and the opposite upper side for the hopper, by means of an oxyacetylene torch. The pipes are set on an incline, approximately 30°, and ore is charged through a hopper at the upper end. The charge half fills the pipe, which is closed at the lower open end by a plug of burned ore stacked in such a way as to let a little air draw through it. Two bricks are used to help stack the burned

40/ Personal communication.

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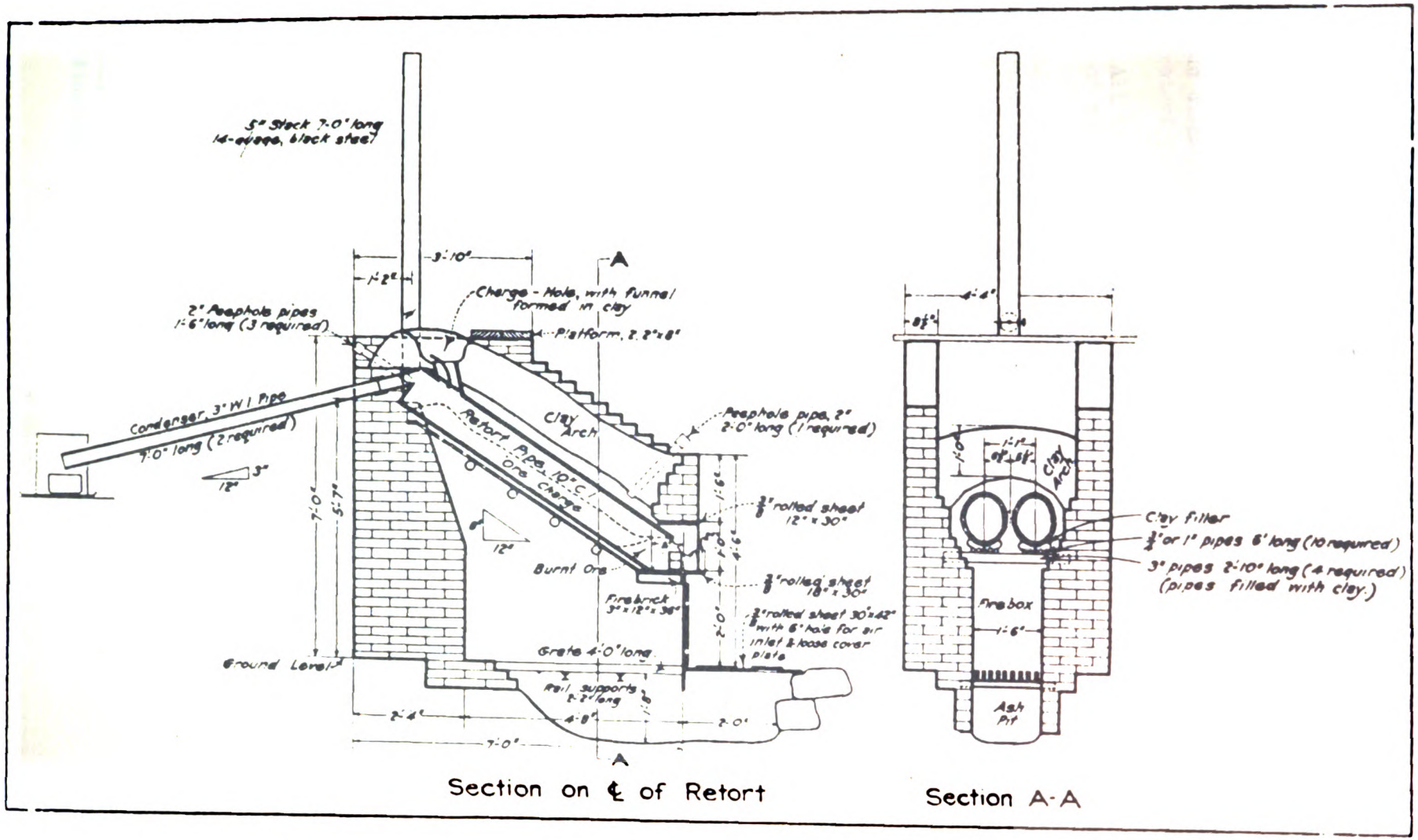

Figure 15.—Rossi single-unit, two-pipe, half-ton-daily-capacity mercury retort.

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ore in plugging the lower end of the pipe. Damp ashes and clay are used to pack around the charging hole of the upper end of the pipe. The pipes are directly exposed to the fire in a box built so as to heat them evenly, end to end. Mercury vapors are condensed in an 8-foot pipe with a hood at the lower end and an iron pot to collect the mercury. This condenser pipe, 3-inch inside diameter, set on an incline of about 14°, is connected to the retort pipe with a 10-inch nipple.

All of the retorts of this type that were in use at the time of visit were using wood as fuel. The fuel consumption is said to be exceptionally low - one-third of a cord of wood per ton of ore. Gas, oil, or coal may be used. Banks of more than two pipes can be made. A 6-pipe bank should be made by lining up three units of two pipes each, all in a single frame but with three fireboxes. A 10-pipe bank can have one large firebox and a set of flues with dampers passing under and over the pipes. The retort frames are made partly of masonry with inside liner of common brick. The retort could be built partly into the side of a hill to save masonry.

The capacity of a 2-pipe retort is said to be 1/2 ton of ore daily. The recovery is said to average over 90 percent when firing is done properly. The pipes are charged and the fires stoked every 6 hours, or four times daily. No attention is necessary for the small unit retorts between times.

The advantages claimed for the Rossi retort are quicker and more complete reduction of the ore because of the slope of the pipe and the natural draft from pipe to condenser; less soot, crust, or mud, and cleaner mercury, because the air inlet provides enough oxygen to combine with sulphur vapors, which then pass out as dioxide; and more safety from gases because they can escape only at the condenser end. It is also said to be especially adaptable in treating mercury ores containing pyrite.

In Nevada. - Mining and treatment of mercury ore at the Pershing, Nev., property is described by Adamson[41]. As this is a fairly large property, using large equipment, and as this present paper is written for operators of small mines and plants, the method of treatment adopted here will be given briefly: Ore is crushed by a jaw-breaker set at 1 1/2 inches, and its product is fed to a 1/2-inch vibrating screen. The oversize is fed into a 4 by 60-foot Gould rotary furnace, which calcines 50 tons a day, and the undersize is calcined by an 8-hearth Herreshoff furnace at a rate of 85 tons a day. Both furnaces are oil-fired and use, respectively, 7.2 and 5.4 gallons per ton of ore. Dust is settled in cyclone arresters, and the mercury fume is condensed in metal pipes. The entering gas has a temperature of around 470° F.

41/ Adamson, W. G., Recent Progress in the Metallurgy of Quicksilver: Eng. and Min. Jour., vol. 128, 1929, pp. 503-505 and 508.

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In the Sodaville district, Mineral County, Nevada, are installations of two and three-pipe retorts and one and two D retorts. The two-pipe furnace of 3 tons daily capacity at the Reward mine consists of two 12-inch pipes, 12 feet long, placed vertically in an oil-fired furnace.[41a]

In Texas. - As so little recent information is available concerning operation in Texas, the general description of the mining and metallurgy in the Terlingua district of Alpine, Tex., by Richards[42] is of interest. He spent a week in the district gathering such information as was permitted. The State imposes a royalty of 6 percent on the mercury produced.

Treatment of the ore is, briefly, as follows: Sorting is done at the shaft mouth. At the Chisos Mining Co.'s property, a Scott furnace of 25 tons daily capacity is fired with producer gas made from a sub-bituminous coal mined 7 miles north of Terlingua Creek. A fair recovery of mercury is made. The Waldron mine has a 12-ton Scott furnace fired by dried stalks of the lechuguilla plant, one of the yucca family. It is contended that it is cheaper to gather these plants and sun-dry them than to haul expensive fuel 90 miles from Alpine. The stalks make a hot fire but they burn quickly. At the Rainbow mine, a Nichols-Herreshoff multiple-hearth furnace of 12-ton capacity is fired with oil hauled from Alpine in motor trucks. Final recovery of mercury and soot is said to be wasteful. A picture of the drying hearth shows ore of about 2-inch size. The Study Butte mines of Southwest Mines are producing ore of 0.5 percent grade. It is sorted, crushed, and calcined in a 35-ton Gould rotary furnace. Recovery is good, but milling and flotation are being tried to increase it.

Bottling Mercury

The mercury recovered from the condensing system should be clean and remain bright in contact with the air. If there is a film or scum on it, this indicates contamination with some base metal, as zinc, which oxidizes slowly on exposure to air. Bubbling air through or stirring the metal will remove much of the impurity, which will appear as a scum and can be skimmed off. At some mines the mercury is filtered through chamois skin. When the metal is quite clean it is ready for bottling in the regular 76-pound flask. This container costs 45 to 80 cents and has a screw-plug which is dipped in red lead in oil to make a tight joint. Before filling the flask, the exact quantity should be carefully weighed. A special iron weighing bucket (fig. 16), with spout that fits into the flask top, should be used. Mercury cannot be carried around in ordinary buckets; also, it is not easy material to carry in an open container because of its dead weight and mobility.

41a/ Vanderburg, William O., Work cited, (footnote 14a).

42/ Richards, Allen, Cinnabar Mining in the Terlingua District: Min. Jour. (Arizona), vol. 20, Nov. 15, 1936, pp. 3-4, 34-35.

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Figure 16.— Mercury bucket for filling flasks.

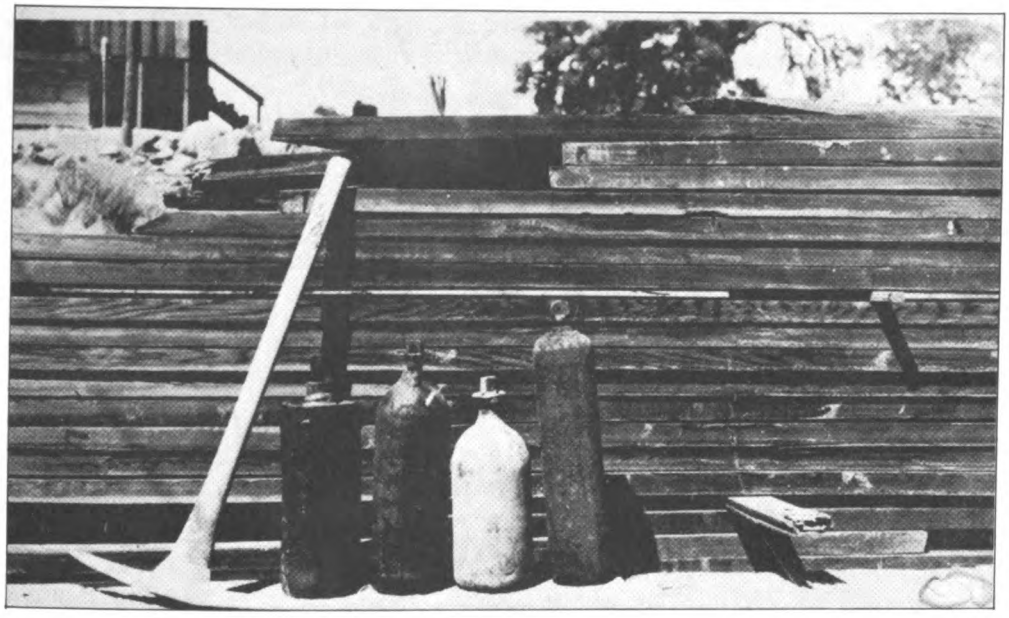

Figure 17.— Four types of mercury flasks. From left to right: The old hand-forged Norway iron flask, the last made about 1890; the so-called "Almaden" flask, made in Germany for the Almaden mine in Spain, which uses only new flasks; the Mannheim flask, made in Austria and used almost exclusively at Amiata and Idria mines in Italy; the Californian flask, made in San Francisco of 4-inch outside-diameter casing with spun bottom and pressed and welded top, 4 to 6 pounds lighter than imported flasks. (25,000 were made during the World War and 15,000 in 1929.) Picture from H. W. Gould, San Francisco.

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Rapid cleaning of mercury, which may be mixed with grease, metallic impurities, floor sweepings, and other material, may be done as follows, according to H. F. Easly, University of Pittsburgh, in a note to the Analytical Edition of Industrial and Engineering Chemistry for February 15, 1937:

Take a 500-ml. glass-stoppered wide-mouthed bottle and fill half-way with dirty mercury; add 25 to 50 grams of mercurous nitrate crystals with about 10 ml. of water and shake for about 5 minutes. Pour out into a dish and allow the water from a faucet to wash away the impurities. Then pass the mercury through several folds of toweling to dry it and it is ready for use again.

As mercury is one of the least active of the metals, it is assumed that the metals in the mercury, as impurities, replace the mercury in the compound $HgNO_3$:

$$Cu + 2HgNO_3 \longrightarrow Cu(NO_3)_2 + 2\ Hg$$

The cleaning mixture will stain the hands black if allowed to touch them.

Treatment Problems

Effect of sulphur

Some mercury ores are not simply cinnabar-bearing; they may also contain sulphur, as at the Sulphur Bank mine, California. There, the partly altered basalt has 1 to 15 percent of free sulphur, with an average of 2 percent. The ore is highly acidic and the action of this acid on the gangue causes a large amount of slime to form. The sulphur is a deterrent to the complete separation of the mercury, as part of the sulphur and mercury recombine in the condensers and form synthetic cinnabar, which has to be retorted. Treatment is now one of sorting the ore, calcining in a rotary kiln, precipitating most of the dust carried from the furnace in the gas stream, condensing mercury from the latter, and retorting the high-grade condenser mud and the high-grade flotation concentrates, making finished mercury.

Losses

There are losses in every type of ore treatment, and mercury is no exception; at the same time, Duschak and Schuette[43] point out that there are no inherent difficulties that prevent the recovery of at least 96 to 99 percent of the mercury vapor entering the condenser system. Their conclusions were derived from tests made at ore furnace at the New Idria mine and two furnaces at the Oceanic mine, California. The former was calcining 70 tons and the latter 90 tons per day of 24 hours. Mercury is lost by means of water

43/ Duschak, L. H., and Schuette, C. N., Fume and Other Losses in Condensing Quicksilver from Furnace Gases: Tech. Paper 96, Bureau of Mines, 1919, 25 pp. (Out of print.)

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in the condensing system, by gas leakage, by absorption, and mechanically. Much metal has been lost and eventually recovered from the hearth furnaces of the Scott type, formerly in general use at large mines.

Poisoning

The problem of mercury poisoning is dealt with in a later section.

CONCENTRATION OF MERCURY ORES

In general, the direct roasting or calcining of mercury ores is preferred and is the universal practice, but many more or less serious experiments and mill runs have been made on concentration; yet, apart from the wet-dressing of dump ore at New Idria, Calif., and a few small operations in that State, little concentration is practiced.

Bradley

Bradley[44/] devoted 86 pages to the concentration of mercury ores. He concludes that the ultimate decision between a straight furnace reduction and concentration and roasting of concentrates will be a matter of comparative costs coupled with comparative extractions. The concentrates have to be calcined to get the final desired product - metallic mercury - and the treatment of such concentrates is not simple. One workable method is to dry them at 110° F. in a rotary kiln set at low inclination and driven slowly, then to feed them into the calcining furnace with more or less rich ore.

Bradley conducted a number of concentration tests on mercury-bearing materials in the mining laboratory of the University of California. They consisted of ores, discarded waste rock, fines, serpentine, and tailings assaying 0.14 to 5.96 percent mercury. These were crushed dry by rolls through 6 to 20-mesh and the pulp was passed over concentrating tables. As cinnabar is very friable, grinding was avoided.

Tabling

It was found that the feed to tables should be classified first; paint or slimed cinnabar is not recoverable by tables, as such material remains in suspension or floats off; a friable sandstone containing disseminated cinnabar is well suited to table concentration, giving 92 percent recovery and 32 percent concentrates; some of the other materials would have given higher results with favorable manipulation; native mercury is readily recoverable on tables, though large globules tend to roll around and jump the riffles instead of advancing along them.

One interesting test was that of soft serpentine carrying 0.51 percent native mercury and distinctly crystalline cinnabar, the total assay being 1.39 percent mercury. The differences in the specific gravities of the several heavier constituents of this ore were well illustrated in the classification

44/ Bradley, Walter W., Work cited (footnote 34).

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shown on the table at the concentrate discharge: At the back, first came the native mercury (sp. gr. 13.6), next the cinnabar (sp. gr. 8.1), then a black mineral, probably magnetite (sp. gr. 5.17), and finally pyrite (sp. gr. 5.0) in the edge of the middlings. The total recovery was 78 percent, with a concentrate assaying 4.48 percent mercury.

Flotation

Bradley made a considerable number of flotation tests at a time when there were not so many reagents as now and the art was not as advanced. The ores assayed 0.14 to 5.96 percent mercury and all the test details are tabulated, good, bad, and indifferent. The highest recovery was 86 percent, and several were above 80, 70, and 60 percent. Most of the tests were on 100-mesh material, a few of minus 200-mesh. It was found that colloidal slime (ocher) covered or enclosed the metal sulphide, thus preventing access of oil to them. The addition of caustic soda improved this condition. When crushed, serpentine produces considerable slime. The best result, 86 percent, was on 100-mesh 0.49 percent ore, but a metallurgical firm got 90 percent from minus 40 plus 80-mesh pulp, floating first and then tabling.

A fourth of Bradley's chapter on concentration is given to practical applications of tabling and flotation in California from 1871 to 1917. He argued that on the basis of relative density it does not appear reasonable that cinnabar cannot be concentrated successfully. And so, during this period many small and crude to large and elaborate mills and concentrating plants were built, run, dismantled, and remodeled. But there have been many changes since the publication of Bradley's Bulletin 78, 20 years ago.

Current concentration in California

Writing to the authors in January 1937, Bradley states that all calcining is preferable, if for no other reason than that it is more simple than concentration and calcining concentrates, but in the final analysis economics is the deciding factor. This is the reason why none of the larger California operators is today using concentrating equipment. Bradley gave the Bureau of Mines the names of several operators at small mines in California where several forms of concentration are being used. These were solicited for information, and the following replies were received:

Lake County

The Oat Hill Mine, near Middleton, Lake County, Calif., according to Zack Anderson, produces a light gray sandstone that is mostly soft and gritty. The cinnabar, which is coarse and granular, is evenly disseminated, and the mercury content of the ore is 3 to 5 pounds per ton. No sorting is possible with this type of ore.

The mill, of which Anderson supplied a flow-sheet, is run one 8-hour shift a day and handles about 1 ton per hour. It consists of a 6- by 8-inch Straub jaw-crusher; Joshua Hendy 16- by 10-inch rolls that reduce the ore to 6-mesh in circuit with a vibrating screen; a Deister table whose concentrates are retorted and whose tailings are separated in a cone into slime and sand, the former passing to a rebuilt standard table whose concentrates are retorted. The approximate recovery is 85 percent and the concentrates contain

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50 percent mercury. They are calcined in pipe retorts, 100 pounds being mixed with 30 pounds of processed lime for each retort. The cost of milling and retorting is $1.12 per ton of ore. A contemplated addition to the plant was a rod mill and two slime tables to deal with the cone underflow.

Sonoma County

1. At the Cloverdale mine near Cloverdale, Sonoma County, Calif., according to Evan Bennett, the ore (a chert averaging 0.8 percent mercury) is mined by glory-hole methods. The top of the opening is at an 1,620-foot elevation, and the bottom, which connects with an adit 500 feet long, is at 1,486 feet. The daily output is 70 tons. No crushing is done. The ore is washed in a 2 1/2- by 20-foot trommel having 1/2-inch holes. The coarse material is trammed to dump, and the undersize passes to a 30- by 72-inch vibrating screen with 1/8-inch holes. This product is concentrated on a Deister standard table whose concentrate assays 45 percent mercury. The recovery is 50 percent and the cost is $60 per flask. Concentrates are calcined in a D retort.

2. At the Esperanza mine, near Cloverdale, Sonoma County, Calif., according to James G. Cortelyou, who sent a plan and side view of his mill, the ore is a soft sandstone with mercury in the form of 80 percent native metal and 20 percent cinnabar. The average mercury content is 9 pounds per ton. Last year, 600 tons were milled at a cost of $2 per ton. The flow-sheet is as follows: The rock is fed onto a double shaking screen with 3/16 and 1/16-inch holes and water-sprays. Sorting is done as the rock passes the screen, 50 percent being discarded. The plus 3/16-inch ore is reduced further in a crusher and rolls and is returned by bucket elevator to the screen. The final undersize flows through a long tom or trough, over a bumping table and carpet-lined troughs. Most of the mercury metal is trapped at the head of the long tom. The approximate recovery is 80 percent. The concentrates average 50 percent mercury and are roasted in a pipe retort heated by wood fuel.

Coghill

W. H. Coghill, of United States Bureau of Mines, wrote to the author recently that he had floated cinnabar from Oregon at the Northwest Experiment Station in Seattle, Wash., in 1917. With a little pine oil as reagent, he produced a rich concentrate and poor tailing. Occasionally since then he has tested mercury ores and found them readily amenable to flotation. At a mine in Mexico he has observed the flotation of ore, by adding creosote and pine oil to the ball-mill and xanthate and aerofloat to the classifier overflow. The ore is ground to 65-mesh and the concentrate assays 40-percent mercury.

Coghill does not believe that gravity concentration will be very adaptable to mercury ores in the United States, and in their flotation is a problem that possibly has not been investigated - the retorting of the muddy products of flotation. They should first be cleaned, perhaps three or four times. Probably this would occasion additional loss, but a more attractive concentrate and one easier to handle and retort would result.

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Duschak and Schuette

In the section of their Bulletin 222 devoted to concentration and wet treatment of mercury ores, Duschak and Schuette[45] say:

> It was natural that the application of methods for the concentration and wet treatment of ores of copper, zinc, and others should stimulate interest in applying these processes to the winning of quicksilver. Attempts to concentrate cinnabar ore were made as early as 1871, * * *. It may be stated, in general, that attention given to these subjects, and particularly to concentration, is quite out of proportion to the results that have been achieved so far [1925], and if the subject had been examined carefully from an economic aspect, in advance of practical attempts to treat quicksilver ores by milling operations, it is likely that a good deal of time and money might have been saved.
>
> * * *. It was thought that concentration might be applied to advantage in procuring a rapid increase in quicksilver production in connection with regular furnace-plant operation. * * *. A number of mills were constructed in California, but most of them were poorly designed, hastily erected, and not well operated. * * *. Correction of these defects should have improved results materially, but would not have altered the fundamental economic situation. * * *.
>
> The only large mill that was operated for any extended period was that at the New Idria mine, San Benito County, Calif. * * *. It is doubtful whether the recovery exceeded 60 percent. One of the principal sources of loss was the slime. [Later improvements increased the recovery to 66 percent.]
>
> ***. It is extremely doubtful whether there is much of a field for concentration in quicksilver metallurgy. One obvious disadvantage is that the mill product requires further treatment before quicksilver is obtained. A jig or table concentrate can be readily dewatered, dried, and treated either in a retort or by incorporation in a furnace charge, as was the practice at the New Idria plant. A flotation concentrate, on the other hand, is likely to be difficult to handle. At New Almaden, where flotation was practiced for a short time, the concentrate was like mud and gave considerable trouble in drying and subsequent treatment.
>
> Viewed broadly, the simplicity of the furnace treatment of quicksilver ore and its low cost, combined with the fact that a finished marketable product is usually obtained in a single operation, leave little opportunity for the economical application of concentration.

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[45] Duschak, L. H., and Schuette, C. N., Work cited (footnote 3).

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***. The higher recovery that can be obtained with a furnace plant more than offsets any slight saving in the cost of ore treatment through milling.

Gaudin

Gaudin[46] states that for practical purposes the problem is largely one of separating cinnabar from associated impurities, mainly fine gangue and sulphur, and to make a clean tailing. He recommends the use of subaeration flotation cells. If sulphur is present, it should be removed first by kerosene; subsequently, aerofloat or xanthate suitably collect the cinnabar. In one instance a concentrate of 62.8 percent mercury and tailing of 0.01 percent were produced from an ore containing 0.35 percent, indicating a recovery of 97 percent of the mercury. In another case, nearly 98 percent was recovered in a 43-percent concentrate from 1.05 percent ore.

Gould

H. W. Gould, San Francisco, whose specialty is mercury, recently gave the following information to the United States Bureau of Mines regarding the concentration of mercury ores:

> In this country, to date, only four real attempts have been made to concentrate mercury ores and, from a recovery basis, they have all been poor. At the Oceanic mine, in 1916, a 200-ton mill was installed, using gravity concentration with sand and slime tables. It worked only 14 days and was considered a failure. At the New Idria mine, San Benito County, Calif., at the same time, a 500-ton plant was built and operated about 18 months. Economically, this plant was a success, but from a recovery aspect it was not and was closed down in 1917, when the large rotary furnace plant was installed. About 73 percent was recovered. The plant consisted of a jaw-crusher, an 8- by 6-foot Allis-Chalmers ball mill, a Richards hydraulic jig, and double-deck Deister sand and slime tables. Later the slimes were floated in an old Callow flotation plant.
>
> The writer was the manager of the New Idria at this time, and also of the Sulphur Bank mine in Lake County, where we put in a plant of 700-ton daily capacity, merely screening dump material, tabling, and retorting. The recovery at this plant was seldom over 40 percent, but, on account of the high price of mercury during the World War, it was profitable. Six or seven years ago the Sulphur Bank mine, by another company, erected a large flotation plant, about 300-ton capacity, but it is the writer's understanding it ran only a short time.

46/ Gaudin, A. M., Flotation: McGraw-Hill Book Co., New York, 1932, pp. 338-339.

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H. W. Gould & Co. has made flotation tests on 100 or more cinnabar ores and, without exception, the results have been poor. Larger tests on freshly ground ore usually are fair, but milling results usually are poor. It is difficult to give a reason for this, except to say that mercury ores are, as a rule, erratic in their occurrence and often carry, in varying amounts, mineral salts that upset the operation, causing violent frothing at times and at other times little or no frothing. Generally, it is found that the difference in recovery between a furnace plant and a flotation plant is sufficient to cover the entire cost of furnacing, as a difference of even 10 percent in the recovery on a 7-pound ton ore is enough to do this. In substantiation of this remark, there are 100 mercury furnace plants in the United States and Mexico without a single milling operation. [The U. S. Bureau of Mines has since learned of a small mill and flotation plant in Mexico and the small plants in California.]

At the present time, H. W. Gould & Co. is concentrating, at the New Idria mine, some old burned dump ore and furnace residues containing mostly free quicksilver. There is a large quantity of this - 200,000 to 400,000 tons - and underlying the site of the old Scott furnaces is a fairly large tonnage of sandstone, shales, and clay, which is more or less impregnated with free mercury caused by leakage of the old furnaces and condensing systems. This area is about 100 by 400 feet, and the Company is working at one point with a power shovel 80 feet beneath the old condensing system. The material - broken sandstone, shales, and clay - is picked up with a 1-1/4-cubic-yard power shovel and trucked to a 1,000-ton steel bin, thence by conveyor belt to a 4- by 30-foot trommel screen, whose upper half has lifting bars to break up the material, and the lower 10 feet is covered by punched plate perforations of 1/2 inch, which is covered by 1/4-inch mesh wire screen. The material passing through the screen goes to a large duplex Dorr classifier, the slimes from which are passed over a carpet plant 4 feet wide and 200 feet long to a 50-foot thickner, from which the water is returned to the circuit. The sands from the classifier go to two Pan-American hydraulic jigs, thence to riffles. Most of this material carries free mercury.

When working the burned-ore dumps the operation will be the same, except that the minus 1/4-inch material after passing over the hydraulic jigs will be tabled, making a low-grade concentrate - 6 to 15 pounds per ton - which will be carried by conveyor belt to the furnace plant.

The recovery on the free mercury is low and will probably be more so when we start working the old burned-ore dumps. The sandstone and shales yield in free mercury about one pound per ton, but they can be worked very cheaply. On the burned-ore material we do not know what the recovery will be, but doubtless it will be low.

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Tyler and Hayward

Following is what Tyler and Hayward[47] say under a subhead Pure Minerals Easily Reduced:

> Quicksilver is an outstanding example of a metal that can be extracted from its ores with maximum facility by fire methods. Flotation has been employed for beneficiating quicksilver ores, but the field for mechanical treatment obviously is limited where other methods exist for treating economically ores carrying as little as 5 pounds of metal per ton. Fire methods, in this case, are extraordinarily efficient because there is no need to fuse the waste rock, no fluxes are needed, and, temperatures being low, little fuel is required. Moreover, the metal itself reduces easily and collects in a fairly pure condition.

PRODUCTION

As will be seen from the table following, taken from Minerals Yearbook and Mineral Resources of the United States, mercury production of the United States has been irregular. Imports from Italy and Spain were similarly irregular - as our output increased, imports from them decreased, and conversely. The duty on mercury is 25 cents a pound or $13 per flask and 12 to 30 cents on the flask itself.

Mercury production of United States, flasks

Year	Quantity	Year	Quantity
1910	20,601	1923	7,833
1911	21,256	1924	9,952
1912	25,064	1925	9,053
1913	20,213	1926	7,541
1914	16,548	1927	11,128
1915	21,033	1928	17,870
1916	29,932	1929	23,662
1917	36,159	1930	21,553
1918	32,883	1931	24,947
1919	21,415	1932	12,522
1920	13,392	1933	9,669
1921	6,256	1934	15,445
1922	6,291	1935	17,518
		1936	16,569

California's contribution to the United States output is now, roughly, a half; at one time it was nine-tenths.

The foregoing table reveals the fact that if prices for mercury and conditions are favorable, the United States can produce much more than at present. It has been said that it is profitable to mine mercury ore when the price is around $1 a pound, as it has been for more than 4 years.

47/ Tyler, Paul M., and Hayward, Carle R., The Economic Significance of High-Grade Concentrates: Min. and Met., vol. 17, 1936, p. 564.

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MARKETING

Gould has fully covered the marketing of mercury in two publications,[48] but because these may not be available to readers of this Circular, some excerpts from these are given:

> Wherever gold is produced, a market for quicksilver will be found [but not so much as formerly, because of the greater use of corduroy].
>
> The primary market for quicksilver in the United States is San Francisco. New York is a market in which quicksilver is resold. In Europe, the primary markets are London, Madrid, Trieste, Rome, and Leghorn. Secondary markets, or markets in which quicksilver or its products are sold to consumers and others, exist in all large cities and wherever there are chemical supply houses.
>
> Stocks of quicksilver are carried at times by producing companies, by sales agents, and often by speculators. The production of quicksilver in the United States is influenced largely by competition from foreign producers. Without this competition, the domestic production would or could provide the entire domestic consumption and also the relatively small volume of exports.
>
> Small producers are unorganized and must take their chances with traders and agents, or, where they can establish connections with the larger producers they may dispose of their product through them with greater advantage to themselves. Usually, the lots handled by the small producer are so small, and his knowledge of the avenues through which his product may be marketed is so slight, that he cannot profitably undertake the marketing himself.
>
> Quicksilver is shipped on consignment by agents or by the large producers. It is sold on commission, the basis of sale by agents being usually 2-1/2 percent of the selling price. The small producers sell to agents, who, if they practice strictly as agents, sell on consignment. Some agents occupy the dual role of both traders and agents. As traders, they pay cash to the small producer; or, if he prefers, they will sell on consignment for a percentage of the selling price.
>
> The three chief marketing places - London, New York, and San Francisco - present quotations that differ in moderate degree. Practically all the quicksilver sold in San Francisco is finally sold in New York, except that sold for export from San Francisco. Texas quicksilver is nearly always shipped

48/ Gould, H. W., The Marketing of Quicksilver: Eng. and Min. Jour., vol. 114, Dec. 2, 1922, pp. 1032-1034. Quicksilver: Chapter (pp. 150-156) in The Marketing of Metals and Minerals, by Josiah Edward Spurr and Felix Edgar Wormser, McGraw-Hill Book Co., New York, 1925, 674 pp.

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direct to New York and marketed there. The New York price is usually slightly more than that in San Francisco, although occasionally the reverse is true. The London price is less than either. The Engineering and Mining Journal quotes both the New York and San Francisco prices. Both are obtained from transactions of agents. In San Francisco the prices between the several agents may vary, but an attempt is made to average them. The price quoted is the agent's selling price and not that paid to the producer, which is usually considerably lower, and depends on whether the agents are anxious to buy or to sell.

Publications that quote prices for mercury are the American Metal Market (daily, New York), E. & M. J. Metal and Mineral Markets (weekly, New York), Mining Journal (fortnightly, Phoenix, Ariz.), Engineering and Mining Journal and Metal Industry (monthly, New York); The Mining Journal (weekly, London), The Mining Magazine (monthly, London), and Chemical Engineering and Mining Review (monthly, Melbourne).

Average prices for mercury during recent years have been as follows, according to Engineering and Mining Journal:

New York quoted price for mercury

Year	Per flask	Year	Per flask
1922	$ 58.95	1930	$115.01
1923	66.50	1931	87.35
1924	69.76	1932	57.93
1925	83.13	1933	59.23
1926	91.90	1934	73.87
1927	118.16	1935	71.99
1928	123.51	1936	79.92
1929	122.15	1937 1/ (Sept.)	92.00

1/ Up to $98.

According to Gould, just cited,

Transactions are on the basis of flasks, and no smaller quantity is handled on the primary markets. In secondary markets the quantities vary widely. The market for quicksilver is necessarily narrow, and as it may be stored cheaply without deterioration, it lends itself easily to manipulation, and this often causes sharp fluctuations in price.

The wrought-iron flask is the container handled, and this requires no boxing or other protection. Used flasks generally are obtainable through selling agents. They hold 76 pounds [formerly 75 pounds] to 85 percent of capacity.

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Some of the agents sell mercury in 1-, 5-, and 10-pound bottles or jugs - the Braun-Knecht-Heimann Co., the Belmont Smelting & Refining Co., The Wood-Ridge Manufacturing Co., Inc., and the Quicksilver Producers' Association, listed later.

The flasks used in the mercury business continue in service for many years and, if carefully treated and not permitted to rust, have been known to serve for 50 years. Apparently most of the flasks in the industry are of European origin, having come to this country from Spain and Italy. When empty, they are collected by metal brokers, principally in New York, and are sold mostly to California producers. The present price f.o.b. New York ranges from 45 to 55 cents per flask and the f.o.b. price San Francisco is about 60 cents; single flasks retail there for about 70 to 80 cents.

Some flasks have been made up in San Francisco, but the cost of manufacture apparently exceeds a dollar. The American designed flask weighs about 9 pounds as against 14 pounds for those made in Europe. (See fig. 17.)

Buyers

Following is a list of buyers of and dealers in mercury:

California

Atkins-Kroll & Co., 260 California St., San Francisco. - Buyer of small quantities.
Mrs. J. Blackie, 722 Monterey St., Hollister. - Buyer of small lots from local miners.
Braun-Knecht-Heimann Co., 534 Mission St., San Francisco. - Buyer of metal, mostly from other jobbers.
Coast Chemical Distributors, V. R. Ghinsberg, 550 Sharon Bldg., San Francisco. - A large buyer.
H. W. Gould & Co., 700 Mills Bldg., San Francisco.
Haas Bros. (J. Marx), 209 California St., San Francisco. - A large buyer.
Justinian Caire Co., 573 Market St., San Francisco. - Buy mostly from other jobbers.
Mefford Chemical Co. (Percy Chase), 1026 Santa Fe St., Los Angeles. - A large buyer.
Quicksilver Producers Association (Irving Ballard), 560 Sacramento St., San Francisco. - A large buyer.
Bernard T. Rocca, Pacific Vegetable Oil Co., 62 Townsend St., San Francisco. - A large buyer.
Thalls & Co., San Miguel. - Grocery store and buyer of small lots from local miners.

New York City

Charles Hardy, Inc., 415 Lexington Ave.
Goldsmith Bros. Smelting & Refining Co., 74 West 46th St.

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International Minerals & Metals Corporation, 11 Broadway.
Belmont Smelting & Refining Co., 336 Belmont Ave., Brooklyn.
Metal Traders, Inc., 67 Wall St.
Cuno Sievers, 101 Cedar St.

New Jersey

Wood-Ridge Manufacturing Co., Inc., The, Wood-Ridge.

Chicago, Ill.

Goldsmith Bros. Smelting & Refining Co., 58 East Washington St.

MERCURY POISONING

Mercury poisoning develops from the handling of ore that contains free mercury, from dust and fumes that may escape during retorting the ore and condensing the vapors (likewise in the retorting of gold amalgam), and from the handling of liquid mercury. Ventilation of mine workings, tight joints and hoods in the calcining plant, and personal cleanliness (frequent washing) will lessen the hazard.

Sayers[49] has dealt with the problem of mercury poisoning in a practical way, and some excerpts from his writings follow:

> The danger of the mercurial poisoning of men employed in the mining and reduction of quicksilver ores has long been recognized, and has received considerable attention from quicksilver operators. The betterment of any conditions that call for improvement must obviously depend upon a thorough understanding of the subject. ***.
>
> Cases occur when the ore contains free mercury or the more soluble salts and when the workings are underground and are poorly ventilated, but there are far more cases among the men employed about the reduction works.
>
> Insufficient or improper ventilation of working places, with failure to maintain sufficient draft to prevent the escape of mercury vapor from furnaces, condensers, and retorts, at once creates a condition likely to cause poisoning.

49/ Sayers, R. R., Mercury Poisoning: Rept. of Investigations 2354, Bureau of Mines, 1922, 6 pp. Health Hazards in the Extraction of Quicksilver: Section (pp. 156-165) in The Metallurgy of Quicksilver, by L. H. Duschak and C. N. Schuette, Bull. 222, Bureau of Mines, 1925, 173 pp.

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The hazard at retort operations is the greater, because the mercury is evolved in the retort in the form of a concentrated vapor, and a small leak may permit the escape of a large amount of mercury. When the retort is opened for recharging, it may still contain a certain amount of mercury vapor, and some of it may still be escaping from the charge. Unless the operator thoroughly understands this condition and takes proper precautions, he may easily receive enough mercury to cause poisoning.

In furnace operation there is the ever-present danger from the leakage of mercury-laden gas from the furnace and condenser, but this can be minimized by proper regulation of the draft. In a well-regulated furnace plant the only serious hazard that can not be avoided entirely is in connection with the cleaning of the condenser system, where men unavoidably come in contact with mercury and mercurial soot. [This refers to large plants.] Another source present even in a well-regulated plant is the dust that accumulates on the furnace and condenser, also about the furnace and condenser buildings.

The avoidance of mercurial poisoning depends upon proper control of the workmen. [The bare hand should not be used to dip out mercury from a bottle or dish. ***. Men should not smoke when drawing treated ore from a retort. ***. Food should not be eaten at a retort plant, and hands, face, and mouth should be washed well before eating. ***. Teeth and gums should be cared for. ***. Water and milk should be drunk frequently. ***. Work clothes should be changed before leaving the mine, and a shower should be had while changing.]

There is a wide variation in susceptibility to the poisoning, which may be due to the fact that the tissues of some persons are better able to store mercury in an innocuous form than are the tissues of other individuals.

The immediate cause of industrial mercurial poisoning is the absorption and retention of small quantities of the metal or one of its many compounds for an extended period.

Quicksilver may enter the body through the skin, the gastro-intestinal tract, or the respiratory tract. When applied to the skin it is more readily absorbed if the person is perspiring or if the mercury is impure or dirty. Metallic quicksilver, combined with grease, is absorbed easily. Dry and clean mercury on a dry skin probably is absorbed only with difficulty.

Only a part of the mercury absorbed is retained in the body.

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As ordinarily only small amounts of mercury are absorbed within any one day by a worker around reduction plants, the start of the symptoms is usually slow and insidious.

In men of good constitution and of careful hygienic habits, the following has been found to be the general course of the symptons: First, a loss of appetite, stomatitis, and intestinal disturoances might occur, but not always; then, after a period varying from less than a year to two or three years, or even more, tremors develop.

Tremors generally affect the upper limbs first, then pass to the legs. If the workman continues to expose himself to the mercury, the tremors grow worse and gradually extend to the whole body.

Most patients suffering from industrial mercurial poisoning recover if they are removed during the early stages when there is stomatitis, or even after dovelopment of tremor. [This may be a few weeks or months.]

To prevent or lessen the chance of poisoning by mercury, have mine workings and treatment plant well ventilated, make retort joints tight, exercise care while emptying retorts, don't handle liquid mercury with bare hands, and be careful personally.

Yant and Traubert,[50/] of United States Bureau of Mines, have reported on the use of gas masks where mercury fumes are present. Their findings may be given as follows:

Mercury vapor is similar to any common vapor or gas, and for this reason respiratory protective devices that depend merely on a filtering medium, such as cloth, paper, or sponge, are ineffective for giving protection against mercury except to filter out globules of mercury in mercury mist or mercury-bearing dust. Even in these cases the filter would soon become contaminated and would not only tend to help saturate the air breathed by the wearer with mercury vapor, but would continue to contaminate the air breathed even after the external atmosphere became mercury-free. It would be advantageous, however, to use an efficient filter in connection with an absorbent in a gas-mask canister, the filter being placed so that the air would travel through it before reaching the vapor absorbent. This filter would stop mercury mist, mercury-laden dust, and particles of compounds of mercury, such as oxides or sulphides. Any vapor given off by the material deposited in the filter would be removed by passage through the absorbent.

50/ Yant, W. P., and Traubert, C. E., Protection Against Mercury Vapor Afforded by Canister Gas Masks: Rept. of Investigations 3187, 1932, 11 pp

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The face pieces and breathing tubes of all gas masks used for protection against mercury vapor should be cleaned thoroughly after each period of use and placed where there is no danger that mercury will deposit on the surfaces. Very small amounts of mercury distributed over the surface of these parts will contaminate the air breathed, even though the canister removes the mercury vapor from the incoming air.

The freedom from mercury vapor in the air breathed and the end of the life period of canisters may be ascertained by placing a small piece of selenium sulphide test paper in the face piece or suspending it in the breathing tube. The presence of mercury vapor or leakage of mercury vapor during use will be indicated by a blackening of the paper.

Sayers and Dallavalle[51/] recently reviewed the prevention of occupational diseases, and the following excerpts would apply to mercury plants:

The use of exhaust methods near the source of a hazard has grown rapidly in recent years. Briefly, the control of any industrial hazard by local exhaust is based on the principle that sufficient air motion must be created by a hood or opening at the source of the hazard to reduce the concentration below the threshold limit. ***.

A hood should be so designed that it offers a minimum amount of hindrance to the operator. Due consideration must be given to the nature of the substance to be collected. ***.

The simplest form of respiratory protection device is the respirator. Respirators consist of a face piece covering the nose and mouth, with a filter medium to restrain dust or mist on inhalation. A special valve is provided to facilitate expiration.*** Their effectiveness depends upon the type of filter medium used and the manner in which it fits the wearer.

. Canister masks cannot be used where the gases or vapors are in high concentration. A range of 2 to 5 percent of a given contaminant appears to be the maximum limit.,

It is important to remember that canister-type masks cannot be employed in an atmosphere deficient in oxygen.

Still another type of mask used to protect the worker is the positive-pressure mask [hose mask]. Such masks are supplied with a continuous flow of compressed air from a clean source. ***

51/ Sayers, R. R., and Dallavalle, J. M., Prevention of Occupational Diseases Other Than That Caused by Toxic Dust: Mech. Eng., vol. 57, 1935, pp. 230-234.

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Stratton[52] reviews dusts in general, in mines, quarries, and in plants. He says in part:

***the use of wet tools [drills] does not entirely eliminate the generation of dust.

The items enumerated under Metal Refining - Lead apply here, also. [This refers to mercury and other metals, including the generation of dust while charging and drawing furnaces, transportation of various products, and baghouse operations.]

Exposure to Mercury. - Exposures to mercury may occur in mining the ore, reduction of the ore, and in the amalgamation of gold ores. Exposure is also found in the manufacture of thermometers, vermillion, and other dyes, the felt-hat industry, the treating and handling of furs [carroting]; incandescent-lamp, radio-tube, and other electrical-apparatus manufacture; explosives manufacture; and laboratory work, including that of photographic and research laboratories.

The exposure may be from the dust of the salts of mercury, the generation of fine droplets of mercury together with dusts of other nature, and the vapor of mercury which is generated at high temperature as well as small amounts which may be given off at ordinary room temperature.

For 5 cents the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., will send a 4-page (3-1/2 by 6 inches) pamphlet entitled "Mercury Poisoning; Its Cause and Prevention", issued by the United States Department of Labor. This is a concise statement explaining how mercury poisoning occurs, the signs and symptoms and what to do about it, and preventive measures.

52/ Stratton, Revel C., Toxic Dusts: Their Origin and Source in Various Industries: Mech. Eng., vol. 57, 1935, pp. 95-98.

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